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SHIP DESIGN AND PRODUCTION FACILITIES: COST-EFFECTIVENESS ANALYSIS OF ACHIEVING A 355-SHIP FLEET

Herzig, Bradley M.; Helme, Stuart M.

Monterey, CA; Naval Postgraduate School

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THESIS

SHIP DESIGN AND PRODUCTION FACILITY: COST-EFFECTIVENESS ANALYSIS OF ACHIEVING A 355-SHIP FLEET

by

Bradley M. Herzig and Stuart M. Helme

December 2020

Thesis Advisor:	Ryan S. Sullivan
Co-Advisor:	Simon Veronneau

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13. ABSTRACT (maximum 200 words)

The current goal for the United States Navy is to achieve a 355-ship fleet by 2034 and 500 ships by 2045, according to the March 2020 *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2020*. To achieve this goal, ship service lives will need to be extended and shipbuilding will need to occur. Given the current budgetary constraint, this project explores the cost effectiveness between four approaches to vessel construction: 1) U.S. naval designs built at U.S. yards, 2) commercial and foreign designs built at U.S. yards, 3) foreign designs built at partner foreign yards, and 4) commercial U.S. designs built at foreign yards. The cost effectiveness analysis took into account the need to preserve the U.S. naval industrial base as well as economic benefits and other advantages and disadvantages of U.S. shipbuilding as opposed to foreign shipbuilding for various design types. Based on the Constellation Class Frigate design, analysis indicates that the United States produces warships at a greater cost than its fellow European NATO member states. The United States is also less productive and maintains a lower capacity to produce warships. This analysis provides reasonable evidence to shift production of warships overseas, but it must be done in a balanced way that maximizes the cost-savings and allows the United States to continue to lead the way in next-generation technology.

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Bradley M. Herzig
Lieutenant, United States Navy
BS, Auburn University, 2014

Stuart M. Helme
Lieutenant, United States Navy
BSCE, Purdue University, 2014

Submitted in partial fulfillment of the
requirements for the degree of

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from the

NAVAL POSTGRADUATE SCHOOL
December 2020

Approved by: Ryan S. Sullivan
Advisor

Simon Veronneau
Co-Advisor

Amilcar A. Menichini
Academic Associate, Graduate School of Defense Management

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ABSTRACT

The current goal for the United States Navy is to achieve a 355-ship fleet by 2034 and 500 ships by 2045, according to the March 2020 *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2020*. To achieve this goal, ship service lives will need to be extended and shipbuilding will need to occur. Given the current budgetary constraint, this project explores the cost effectiveness between four approaches to vessel construction: 1) U.S. naval designs built at U.S. yards, 2) commercial and foreign designs built at U.S. yards, 3) foreign designs built at partner foreign yards, and 4) commercial U.S. designs built at foreign yards. The cost effectiveness analysis took into account the need to preserve the U.S. naval industrial base as well as economic benefits and other advantages and disadvantages of U.S. shipbuilding as opposed to foreign shipbuilding for various design types. Based on the Constellation Class Frigate design, analysis indicates that the United States produces warships at a greater cost than its fellow European NATO member states. The United States is also less productive and maintains a lower capacity to produce warships. This analysis provides reasonable evidence to shift production of warships overseas, but it must be done in a balanced way that maximizes the cost-savings and allows the United States to continue to lead the way in next-generation technology.

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LIST OF ACRONYMS AND ABBREVIATIONS

CGT	Compensated gross Tonnage
CNO	Chief of Naval Operations
EU	European Union
FREMM	Fregata Europea Multi-Missione
GDP	Gross domestic product
GFE	Government-furnished equipment
HDW	Howaldtswerke-Deutsche Werft
JCIDS	Joint capabilities integration and development system
NATO	North Atlantic Treaty Organization
NRO	Non-recurring engineering
OECD	Organization for economic co-operation and development
PPBE	Planning, programming, budgeting, and execution
R&D	Research and development
SLE	Service Life Extension
UK	United Kingdom
U.S.	United States
WWII	World War 2

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I. INTRODUCTION

As the Navy pushes for a 355-ship fleet by 2034 (Deputy Chief of Naval Operations [DCNO], 2019), and a 500-ship fleet by 2045 (Harper, 2020, para. 6), we continue to see cost overruns and timeline delays. Our project looks to analyze the four different methods of shipbuilding in order to meet the demands of the Navy. We will be focusing on labor, materials, and design price differences when building overseas versus domestically and the potential savings the Navy can put toward growing our fleet. The domestic shipbuilding base contains many flaws and inefficiencies that are highlighted throughout and provide comparisons to the commercial market to develop a globally competitive market. A view into our NATO allies demonstrates their expertise in shipbuilding and an in-depth look at the FREMM class frigate built at a multi-national stage. The domestic market is operating beyond capacity in the military sector at the few remaining shipyards and continues to make acquisition mistakes that cost the taxpayers billions. Our cost-effectiveness analysis will review the acquisition of:

1. Domestic design built domestically
2. Foreign design built domestically
3. Domestic design built overseas
4. Foreign design built overseas

The largest contributors to the construction cost (depending on the level of technological sophistication) are steel and labor. We identify labor costs by GDP per capita and steel price by continental regions to best gauge our cost analysis.

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II. BACKGROUND

A. SHIPBUILDING PROCESS

The shipbuilding process is similar between both commercial and naval warships and consists of four main phases, pre-contract, design, construction, testing, and delivery. The U.S. Navy follows the Department of Defense’s defense acquisition system that consists of three main sections for needs requirements, funding, and project management. These three sections are called the joint capabilities integration and development system (JCIDS), the planning, programming, budgeting, and execution process (PPBE), and acquisition process. These three systems work together to determine the need, design, execution, and delivery of a solution as well as ensure funding and timely completion of the process within the Department of Defense (Office of the Secretary of Defense [OSD], 2015). Figure 1 illustrates the major milestones and steps within the Navy acquisition process. The initial step is the material solution analysis where a physical solution is developed for a capability gap or technology discovery. This phase is also where requirements are developed and culminates with milestone A and the decision to enter into the second phase of technology development. During technology development, initial parameters and requirements are finalized, and bidding for contracts take place. This phase transitions at milestone B where a contract is signed and the project begins. The next phase is engineering and product development where the first prototype and manufacturing process is developed. The conclusion of this phase is milestone C where initial operational test and evaluation and low-rate initial production occurs. The next phase of production and deployment is where full-scale production and deployment of the material solution takes place until all scheduled units are completed. This phase often overlaps with the final stage of operations and support where completed units are placed into operation and maintained throughout their intended lifetime.

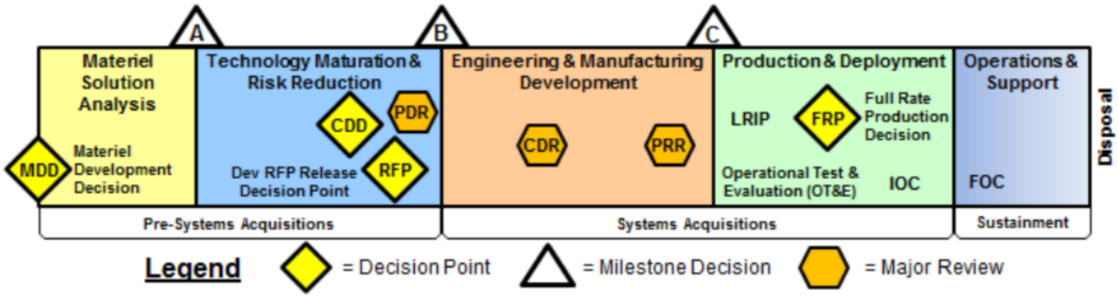

Figure 1. Navy Acquisition Major Milestones. Source: OSD (2015).

Each shipbuilding project is unique depending on requirements. Although commercial and military shipbuilding projects vary in requirements and procedures there are nine basic steps that generally represent a ship's life cycle.

1. Development of Owner's Requirements

The initial stage of ship production is to determine the requirements desired by the customer. These requirements may be broad or narrow but should be designed to meet the intended mission of the ship. An example of commercial requirements may be a ship capable of transporting 10,000 automobiles a year from Japan to the United States. While a military requirement may be an oiler capable of underway replenishment that is capable of operating on short notice around the globe. These are examples of broad requirements but would be included with more specific requirements to make clear to the manufacturer what is expected of the proposed ship (Storch et al., 1995, pp. 2).

2. Preliminary/Concept Design

Once requirements for the ship have been determined the basic characteristics of the ship are determined. Preliminary designs can be completed by outside design agencies, shipyards, or by the owner's staff. The U.S. Navy differs from commercial shipbuilding practice, as it has a large internal shipbuilding design y while domestic U.S. shipbuilding tends to hire outside agents to conduct preliminary design. Preliminary design should determine parameters that best meet requirements but also work best with the capabilities of the shipyard where fabrication will occur. The desired result of preliminary design should meet requirements and enable construction in the most timely and affordable fashion.

> The end product of this stage is a general definition of the ship, including dimensions, hull form, general arrangement, powering, machinery arrangement, mission systems definition (such as cargo capacity and handling equipment, combat systems, or habitability), capacities of variable weights (such as fuel oil, water, crew, and stores) and preliminary definition of major systems (such as structural, piping, electrical, machinery, and ventilation [HVAC]). (Storch et al., 1995, pp. 2)

3. Contract Design

Following the preliminary design phase, the contract design phase gives enough detail and specifics so that firms can bid on the construction of the ship. This means that designs should be adequate to allow firms to estimate costs and time required to complete the project. Similarly, to the preliminary design, the contract design can be conducted by an outside agency, internally, or through a shipyard. It is uncommon for the contract design to be conducted internally for both the Navy and commercial firms (Storch et al., 1995, pp. 3).

4. Bidding/Contracting

Generally bidding is competitive where firms enter bids based on cost, delivery time, and operational requirements. There are instances within both the commercial and military sectors where bidding is not competitive and a contract is exclusive. An exclusive contract may be the result of a capability only being met by a single firm or if a shipyard or firm was hired through the design process (Storch et al., 1995, pp. 4).

5. Detail Design and Planning

Upon completion of the contract, a detailed design is created to answer what, where, and how, and by whom. This takes into account raw materials, personnel, transportation, facilities, budget, and sequencing. Ensuring a detailed and considerate detailed design and planning process is crucial to the completion of a ship on time and within budget. The greatest contributor to project delay is added work which is a result of inadequate design and planning (Storch et al., 1995, pp. 5).

6. Construction

Ship construction can be further broken down into four tiered processes. First, is parts manufacturing where raw materials are fabricated into component parts. Second, these parts are combined to make subassemblies or units. The third level of assembly is where these subassemblies are joined to make hull blocks. Hull blocks are the largest components of the ship and are generally fabricated separately. The final stage of construction is where the hull blocks are joined to create the completed ship. During this final stage, all sections are continuously tested to ensure design requirements are met (Storch et al., 1995, pp. 6).

7. Test and Trials

Upon completion of construction, the ship is tested to meet requirements. This includes dock trials and sea trials where all of the ship's components are tested within the dry dock and then at sea. Testing and trials are more rigorous for initial designs. Once sea trials are completed the ship returns to correct any deficiencies identified and to make any potential upgrades or design changes (Schank et al., 2014).

8. Operations and Support

Once testing and trials have been satisfactorily met the ship is put into operation. During the lifespan of the operational ship, it requires maintenance and upgrades. Both commercial and military vessels have a planned life cycle of repairs and upkeep. Upkeep can range from short periods of maintenance moored in port to extended periods at dry dock. Within the Navy, each ship receives a program office responsible for the planning and execution of maintenance periods and upgrades until the forecasted retirement of the ship (Schank et al., 2014).

9. Retirement and Disposal

Upon completion of a ship's operational life, it is retired or discarded. Within the commercial sector, this means it is either sold or dismantled. Within the Navy, this means one of three options. Firstly, the ship is either mothballed where it is permanently moored or stored in a nonoperational status. Secondly, it could be sold for foreign military sales.

Finally, the ship could be dismantled and destroyed collecting component parts with remaining value (Schank et al., 2014).

While the process of constructing a warship and a commercial vessel is similar, generally the time needed to complete a warship is significantly longer than that of a commercial vessel, particularly when a new class of ship is being developed. For example, the DDG 1000 program was initiated in 1993 and the first ship of its class, USS *Zumwalt*, was christened in 2014 but is still not operational or in full production (Downey, 2014). This is in contrast to the Oasis Class cruise liner developed by Royal Caribbean International that began in 2003 and launched the first ship of the class, Oasis of the Seas, in 2009 (Ship Technology, 2020). Although the complexities of a warship differ from those of a cruise liner, they are similar in scale and intricacy as the Oasis of the Sea is over ten times the size of the USS *Zumwalt* with an open-air park (Downey, 2014), multi-tiered swimming pool, and life-supporting systems for a crew of 5,400 (Ship Technology, 2020). This difference in project completion time could be attributed to several aspects ranging from differing shipyards, bureaucratic processes, operating requirements, and legal restrictions.

Figure 2 illustrates these phases in three different methods of execution. The life cycle of a warship includes a much earlier and longer overlap during the design and construction phases that has the potential to result in rework, delays, and cost overruns as many recent projects have demonstrated. Commercial acquisition projects tend to follow the no-overlap method and result in a fewer rework delays and cost overruns, ensuring all milestones are finalized prior to commencing follow-on steps.

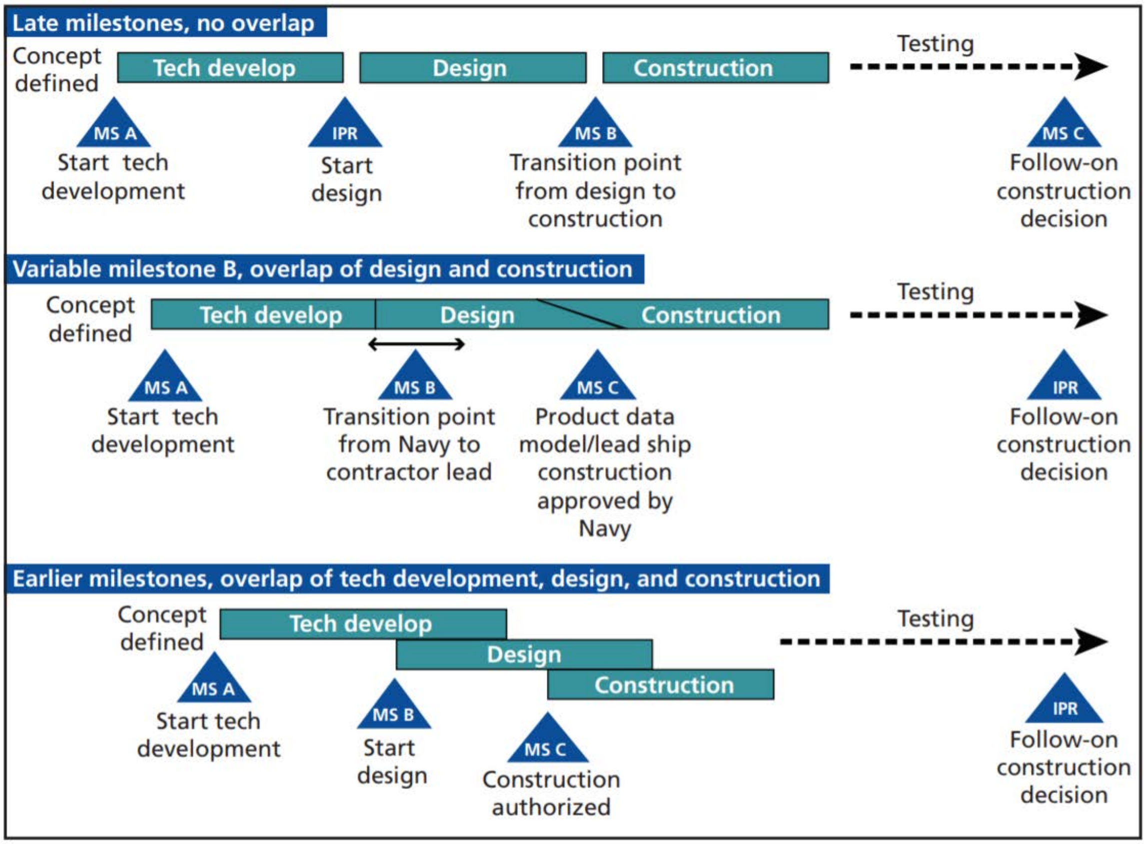

Figure 2. Three Ship Design and Build Alternatives. Source: Drezner (2011).

B. DOMESTIC SHIPBUILDING

The U.S. Navy has released its congressional plan to achieve a 355-ship fleet by 2034 and maintained through 2049 (DCNO, 2019). There is extensive literature detailed in the report to Congress on the *Annual Long-Range Plan for Construction of Naval Vessels* for fiscal year 2020 built through aggressive growth and service life extensions (SLE). The articles include cost analysis, delivery plan, and a brief discussion of the shipbuilding industrial base. Table 1 illustrates the fleet breakdown and the ships required to meet the operational needs of the Navy.

Table 1. Navy the Nation Needs. Adapted from DCNO (2019).

Type	Count
Ballistic Missile Submarines	12
Aircraft Carriers	12
Attack Submarines	66
Guided Missile Submarines	0
Large Surface Combatants	104
Small Surface Combatants	52
Amphibious Warfare Ships	38
Combat Logistics Force	32
Command and Support	39
Total	355

In Tables 2 and 3, Congress details a long-range plan to procure and take delivery of ships over the next 24 years to reach and maintain 355 ships, which is first achieved by FY34 as demonstrated by Table 5. As new ships are delivered, ships are also being decommissioned and removed from the fleet, as shown in Table 4.

Table 2. Long-Range Procurement Profile. Adapted from DCNO (2019).

Fiscal Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Aircraft Carrier	1								1				1				1				1			
Large Surface Combatant	3	2	2	3	3	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Small Surface Combatant	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2
Attack Submarines	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Ballistic Missile Submarines		1			1		1	1	1	1	1	1	1	1	1	1								
Large Payload Submarines																	1			1			1	
Amphibious Warfare Ships		1		1	1	1	1	2	1	1	1	2	1	1	2				1		1	1	1	
Combat Logistics Force	2	1	1	2	1	1	1	1	1	1	1	1	1	1										1
Support Vessels	2	1	2	3	1	2	2	1	1	1	2	2	2	2	2	1								
Total New Construction Plan	12	10	9	13	11	11	11	12	11	11	10	13	12	12	11	9	8	7	7	8	8	8	8	8

Table 3. Battle Force Delivery Plan. Adapted from DCNO (2019).

Fiscal Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Aircraft Carrier					1				1				1					1				1		
Large Surface Combatant	4	2	3	2	1	3	2	5	4	3	3	3	2	3	2	3	2	3	2	3	2	3	2	3
Small Surface Combatant	2	3	2	5	3		1	2	3	2	2	2	2	2	2	4	2	2	2	2	2	2	2	2
Attack Submarines	3	2	2	3		1	3	1	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2
Ballistic Missile Submarines									1			1		1	1	1	1	1	1	1	1	1	1	
Large Payload Submarines																								1
Amphibious Warfare Ships		1		1	1	1	1		1		1	1	1	2	1	1	2	1	1	2	1			1
Combat Logistics Force		2	1	1	2	2	1	2	1	1	1	1	1	1	1	1	1							
Support Vessels	1	2	6	2	1	2	2	1	1	2	2	1	1	2	2	2	2	1		2				
Total New Construction Deliveries	10	12	14	14	9	9	10	11	15	11	12	11	10	13	11	14	12	11	8	12	8	9	7	9

Table 4. Battle Force Retirement Plan. Adapted from DCNO (2019).

Fiscal Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Aircraft Carrier					-1	-1		-1					-1					-1			-1		-1	
Large Surface Combatant		-4	-2		-2	-2	-1	-1	-2	-1						-6	-7	-5	-1	-6	-2	-4		-1
Small Surface Combatant	-3		-2	-6										-1		-1			-3	-1	-1	-2		-2
Attack Submarines	-2	-1	-3	-4	-4	-4	-3	-3	-3	-1	-1		-1			-1			-3	-1	-1	-2		-2
Cruise Missile Submarines							-2	-1	-1															
Ballistic Missile Submarines								-1	-1	-1	-1	-1		-1	-1	-1	-1	-2	-1	-1	-1			
Amphibious Warfare Ships								-1		-2	-1	-1	-1		-3	-3	-1	-1	-1		-1		-1	-1
Combat Logistics Force		-1		-1	-1	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							
Support Vessels		-2	-1		-1	-1	-1		-1	-2	-2	-2		-2	-2	-1	-2	-1	-1	-4	-1		-2	
Total Naval Force Retirements	-5	-8	-8	-11	-9	-10	-9	-9	-9	-8	-6	-5	-4	-5	-7	-14	-12	-11	-8	-12	-8	-9	-7	-9

Table 5. Battle Force Inventory. Adapted from DCNO (2019).

Fiscal Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Aircraft Carrier	11	11	11	11	11	10	10	9	10	10	10	10	10	10	10	10	10	10	10	10	9	10
Large Surface Combatant	94	92	93	95	94	95	96	100	102	104	107	110	112	115	117	114	109	107	108	105	105	104
Small Surface Combatant	30	33	33	32	35	35	36	38	41	43	45	47	49	50	52	55	57	58	59	61	62	61
Attack Submarines	52	53	52	51	47	44	44	42	42	44	46	48	49	51	53	54	56	58	57	58	59	59
SSGNs/Large Payload Subs	4	4	4	4	4	4	2	1														
Ballistic Missile Submarines	14	14	14	14	14	14	14	13	13	12	11	11	11	11	11	11	11	10	10	10	10	11
Amphibious Warfare Ships	33	34	34	35	36	37	38	37	38	36	36	36	36	38	36	34	35	35	35	37	37	37
Combat Logistics Force	29	30	31	31	32	32	31	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Support Vessels	34	34	39	41	41	42	43	44	44	44	44	43	44	44	44	45	45	45	44	42	41	41
Total Naval Force Inventory	301	305	311	314	314	313	314	316	322	325	331	337	343	351	355	355	355	355	355	355	355	355

The defense industrial base includes seven private new construction shipyards operating beyond capacity by 117–153% (Hooper, 2019) and is far less than our primary competitors. Figure 3 illustrates the declining number of domestic shipyards unable to pace the required naval force. The commercial shipbuilding industry is hindered by policy legislation and lack of government subsidies is at a huge disadvantage compared to overseas competitors. There are only three U.S. shipyards currently building ocean-going commercial ships to meet the requirements set by the Jones Act (DCNO, 2019).

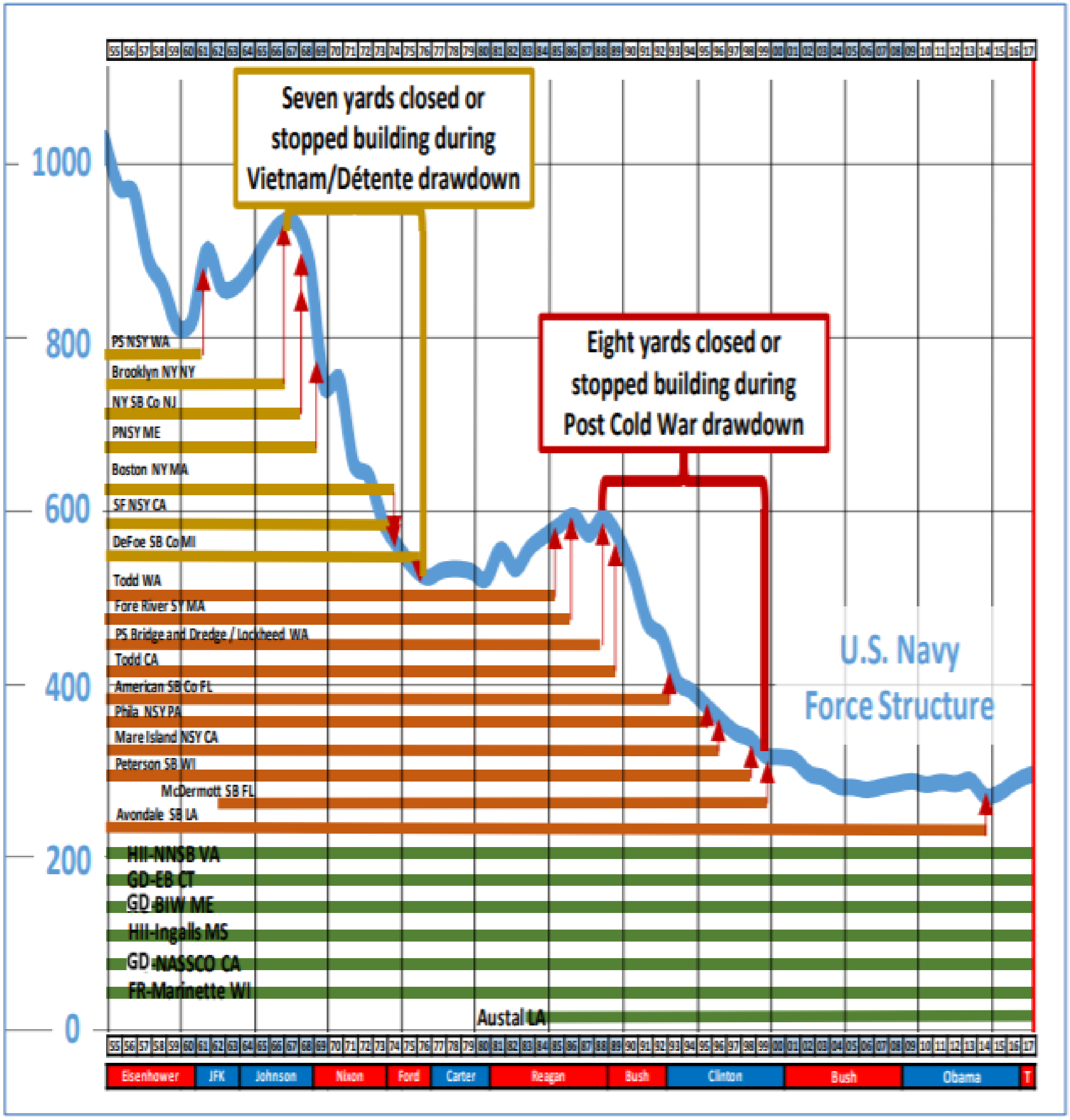

Figure 3. New Construction Industrial Base. Source: DCNO (2019).

The domestic shipbuilding and repair industry support 100,000 direct shipyard labor jobs and contributes $9.8 billion to the national GDP while being nearly 70% reliant on government contracts (Economic Security, 2020). Additionally, for each shipyard job created, there are 2.6 jobs created in the associated domestic supplier base, supporting more than 400,000 jobs, and $36 billion in GDP (Economic Security, 2020). As of 2015, the U.S. ranked 9th in the world with just 0.35% of the world's gross tonnage of new construction with numbers continuing to decline (Klein, 2015). The few remaining shipyards shown in Figure 4 lack the scale, technology, and large volume series building order books to compete internationally. In the absence of worldwide standards, the United States remains handicapped from safety and environmental legislation requiring them to bear excess expenditures (Mumma, 1973, pp. 6–7). The industry has an aging workforce that is unable to recruit young skilled workers and lacks stability in workload due to continuing resolutions.

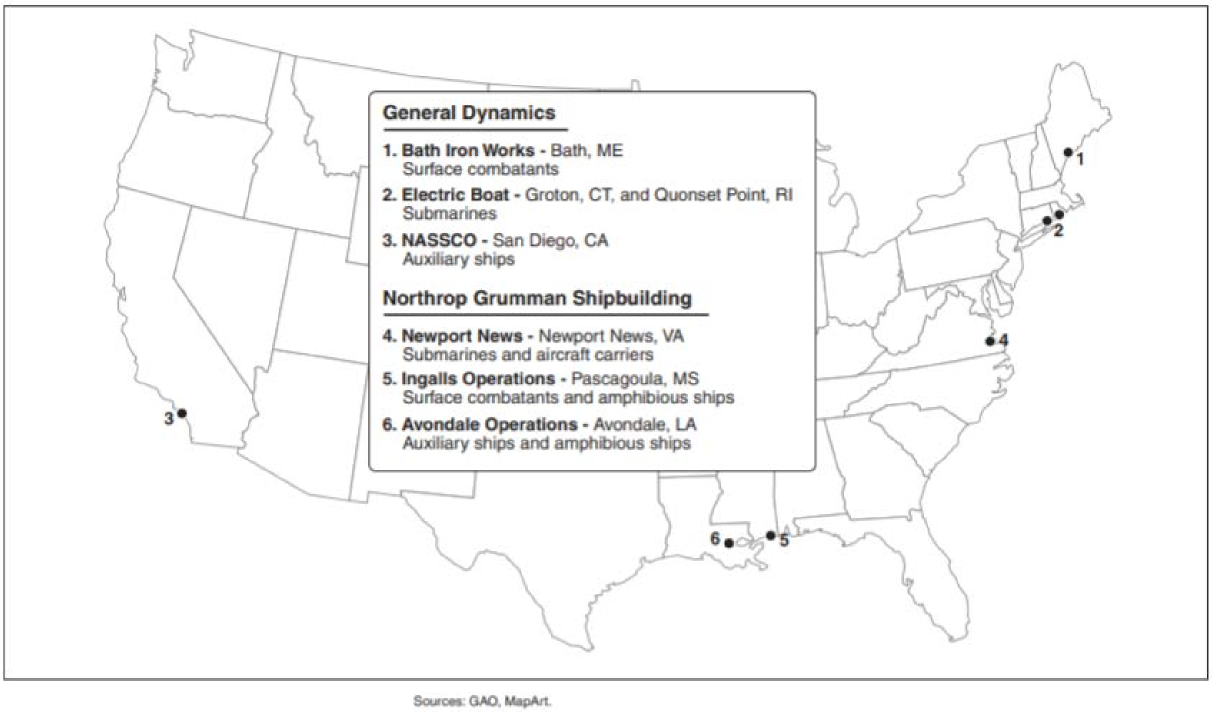

Figure 4. Major Navy Shipbuilders. Source: Francis (2009).

U.S. ships built domestically are proven substantially more expensive than those manufactured overseas (Frittelli, 2019). Domestic buyers are paying the bill for massive subsidies to the shipbuilding sector, limiting the demand for new contracts (Frittelli, 2019). Cost growths contribute to the erosion of the Navy's buying power and delivered ships with less capability and lower quality. "Shipyards had so much commercial work during the Nixon era that for several years, the Navy could not find enough interested shipbuilders to build all the ships for which funds had been appropriated" (Colton & Huntzinger, 2002, p. 13). President Nixon's Commission on American Shipbuilding then made amendments to the Merchant Marine Act of 1936 to include what is known as the Jones Act (Colton & Huntzinger, 2002). The Jones Act is considered protectionist legislation under Section 27 of the Merchant Marine Act of 1920, which regulates maritime commerce in the United States. The act was enacted to stimulate the shipping industry, maintain American political strength, and national security in the wake of World War I. "The legislation includes four primary requirements on vessels carrying goods between U.S. ports. The vessels must be owned by U.S. companies that are controlled by U.S. citizens with at least 75% U.S. ownership, at least 75% crewed by U.S. citizens, built (or rebuilt) in the U.S., registered in the U.S." (Transportation Institute, 2019, para. 2). "This build requirement is met when a vessel is assembled in the United States and all major components of its hull and superstructure are fabricated domestically" (Frittelli, 2019, p. 6). This requirement effectively increases the cost of shipping domestically by restricting the number of vessels that can legally deliver goods to isolated areas. "U.S. builders of large ships are effectively priced out of the world market for merchant ships, the 'Big Six' shipbuilders are highly profitable, with substantial backlogs extending several years into the new century" (Colton & Huntzinger, 2002, p. 22). Limiting the competition to U.S. producers, it limits competition and innovation in a global market. On the other hand, international countries subsidize their national shipbuilding industries, which the U.S. ceased in 1981, to increase capacity (Klein, 2015). Foreign shipbuilding gained the advantage and "U.S. shipbuilding companies have no comparative advantage, impossible for the American shipbuilding industry to compete" (Klein, 2015, para. 6).

C. NATO SHIPBUILDING

By utilizing allied shipbuilders, outsourcing offers several advantages such as alleviating workforce shortfalls, reduced construction costs, and reduced need for new capital investments (Schank, 2005). A decline in the order of both commercial and military ships in the United States is a result of problems meeting the demand from shipyard closures and workforce decline. Thus, a need for outsourcing to increase total labor capacity has arisen to meet future demands. Cost savings come from reduced overheads, lower wage rates, lower costs associated with workforce fluctuations, and improved quality when outsourcing. By moving constructions overseas to more capable shipyards it reduces the need to invest in the modification of existing facilities or construction of new facilities. This can also be seen through the use of subcontractors which reduces the need for large capital investment.

Trends in European shipbuilding are shifting as once dominant shipbuilding nations like Great Britain are taking a backseat in commercial shipbuilding to Asia. The three largest shipbuilding nations in terms of tonnage are South Korea, China, and Japan. This statistic is somewhat misleading though as Europe and NATO members still maintain a significant portion of the shipbuilding market for complex and high-end ship designs such as ferries, cruise lines, and military sales. This means that although Asian nations are producing a greater tonnage of ships, European nations still receive a much greater return on tonnage produced meaning they earn significantly greater amounts per ship than the large tonnage freight ships produced in Asia. NATO members have also seen a shift in its military shipbuilding. Since the Cold War, NATO members have been building fewer, larger, and more complex ships compared to the force structures before the Cold War. Shipbuilding is also realigning within NATO as Turkey and Romania have significantly increased their shipbuilding sectors in recent years. While most NATO members have strict restrictions on military exports, there are only select restrictions in regard to NATO member sales to other NATO members (Birkler et al., 2005). Table 6 depicts military shipbuilding from 2003 to 2012 within Europe. The graphic illustrates how Germany is the largest exporter of military vessels, while the United States and the United Kingdom are the largest producers of military ships for domestic use.

Table 6. Projected Military Ship Production 2003–2012. Adapted from Birkler (2005).

	Export			Domestic Use		
Country	Number	Value ($ millions)	LSW Tons	Number	Value ($ millions)	LSW Tons
Germany	56	10,713	96,040	21	5,799	44,144
France	25	6,405	47,570	17	13,015	146,302
Russia	20	5,000	36,025	0	0	0
Spain	6	2,035	31,343	7	2,195	26,735
The Netherlands	9	1,780	8,500	4	1,585	24,759
United Kingdom	2	650	3,000	22	17,340	235,140
United States	2	53	174	66	56,172	776,446
South Korea	1	30	1,500	7	4,905	24,500
Japan	0	0	0	16	11,090	79,125
Italy	0	0	0	18	5,289	75,170
China	0	0	0	8	3,230	26,875
Australia	0	0	0	1	650	3,051
Sweden	0	0	0	3	375	1,431
Taiwan	0	0	0	1	320	2,769
Israel	0	0	0	11	55	550
Total	121	26,666	224,152	202	122,020	1,466,997
Not Reported	23 vessels valued at $13,225 million and displacing 86,291 tons LSW.					

Before WWII, the United Kingdom was the dominant shipbuilding nation both commercially and militarily in the world. From the 1950s until the present, its commercial shipbuilding industry has weakened, and the vast majority of their shipbuilding industry is supported by domestic military contracts. “As recently as the early 1980s, U.K. commercial shipbuilding represented up to 3% of the world's total. This share fell to 0.3% by 2000 and has been shrinking further" (Birkler et al., 2005, p. 15). "In 1985, government shipbuilding peaked at about 90,000 tons, and again in 1993 at about 120,000 tons. Both of these peaks represented about a third of the total U.K. shipbuilding of those years" (Birkler et al., 2005, pp. 15–16). The British naval shipyard workforce is highly skilled but aging rapidly and is expected to experience severe shortages in skilled labor in the next decade (Birkler et al., 2005). The three major shipbuilders in the United Kingdom are BAE Systems, Swan Hunter, and VT Shipbuilding. These three shipbuilders own or lease 48 facilities capable of major naval shipbuilding (Birkler et al., 2005). The British naval shipbuilding industry does very few foreign military sales and can experience capacity issues when a facility is expected to produce more than one large unit simultaneously.

Germany is the largest European shipbuilding nation and ranks as the sixth-largest shipbuilder globally (Organization for Economic Co-operation and Development [OECD], 2016). Although Germany is a significant shipbuilding nation, they only account for about one percent of the global market and ship manufacturing accounts for a small portion of the nation's economy. "Nine shipyards and around 400 suppliers are active in German naval shipbuilding" (Frank, 2019, para. 5). Germany has conducted the most foreign military sales in Europe in the past several decades but has had greater competition from Italy and France in the past ten years (OECD, 2016). The vast majority of Germany's foreign military sales are also for submarines and subsurface sensors (Frank, 2019). The Thyssenkrupp Group is the largest shipbuilding entity in Germany and is a result of a 2005 consolidation of Howaldtswerke-Deutsche Werft (HDW) in Kiel, HDW-Nobiskrug in Rendsburg, Blohm+Voss and Blohm+Voss Repair in Hamburg, Nordseewerke in Emden, Kockums in Sweden and Hellenic Shipyards in Greece (Frank, 2019). Thyssenkrupp recently made the strategic decision to focus on submarine construction though and has plans to sell most of its surface shipbuilding capacity to German Navalyards Kiel who now produces the majority of German surface ships, primarily frigates and corvettes.

> With approx. 2,700 employees of the Lürssen Werft group of companies, to which the Bremen-based Fr. Lürssen Werft with the Aumund, Berne and Lemwerder divisions, the Lürssen-Kröger Werft in Schacht-Audorf (since 1986), the Neue Jadewerft in Wilhelmshaven (since 2004), the Norderwerft

> in Hamburg (since 2012), the Wolgast-based Peene-Werft (since 2013) and Blohm+Voss (since 2016) belong, has pursued a successful strategy of growth and specialized orientation in recent decades. (Frank, 2019, para. 10)

"Lürssen is the lead company in the K130 corvette joint venture, which also includes Thyssenkrupp Marine Systems and German Naval Yards Kiel" (Frank, 2019, para. 12). Although Germany maintains a large capacity for shipbuilding, its fragmented and restrictive government policy on arms sales have limited the industry's potential (Frank, 2019).

The Naval Group, formerly DCNS, is the major manufacturer of naval ships in France. The group is multinational employing 13,000 employees in 14 countries (Naval Group, 2019). The Naval Group, Fincantieri, and the French and Italian governments recently signed a cooperation agreement between the two largest naval shipbuilding entities in Italy and France. The deal will facilitate cooperation between the two firms on R&D, export strategy, and the FREMM multipurpose Frigate project. This alliance coupled with the United States' decision to pursue the FREMM frigate design for its new FFG(X) platform will make both France and Italy far more competitive within the European Naval Shipbuilding industry (The Maritime Executive, 2020).

Fincantieri is the dominant naval shipbuilder in Italy and the fourth largest single shipbuilding entity in the world after its acquisition of Vard and STX France in 2018 (Howard, 2015). Fincantieri is the designer and manufacturer of the FREMM class Frigate which was the design recently chosen by the United States for the new U.S. FFG(X) Frigate Class (Eckstein, 2020). Italy is also the largest producer of ferries, "the twelfth-largest producer of merchant shipping in the world (fourth in Europe), and has the third-largest European fishing fleet, with the national maritime cluster generating 3% of GDP" (Fronseca, 2014, para. 1). The Italian naval shipbuilding industry maintains a large production capacity and is capable of supporting the manufacturing of varying ship sizes.

The Netherlands also supports a shipbuilding industry about the third the size of Germany. The Dutch shipbuilding industry suffered severe losses during the 1980s but has since recovered to the same level of production as the 1970s. The primary Naval shipbuilder within the Netherlands is Royal Shelde and although the Netherlands produces few warships it maintains a significant capability both in expertise and facilities (Birkler et al., 2005).

D. MATERIAL COSTS

Numerous cost estimation approaches exist and are utilized in combinations for commercial companies and the government to project accurate costs to place appropriate bids. The four most utilized approaches, in order from informal to formal, are the black book, parametric approach, standard ship approach, and the direct analysis approach. The closely guarded black book method taken from experienced cost estimators utilizes formulas, tables, charts, industry trends, and vendor data, in which accuracy is difficult to confirm. This method is best used for the construction of a single of a few ship types and sizes and not so dependable beyond those normally constructed at the yard. The parametric approach estimates system and subsystem costs through spreadsheets and cost estimation programs with common dimensions and propulsion power compared with similar ships. This method is only effective when correlated with similar ships and may not be sufficient for many decisions. The standard ship approach utilizes well-known standard ship designs to quickly develop bids. This method limits changes and does not often meet customers' requirements. Lastly, the direct analysis approach utilizes drawings, bill of materials, vendor costs, and existing quotes but practical only after the late stages of development. Combinations of methods may be used, for example, the "parametric approach may be used for structure, but the engineering approach may be used for owner-specified engine and auxiliary equipment. Cost estimates may be carried out by hand, spreadsheet, or on a computer program, and analysis results may be presented at various levels of detail" (Ross, 2004, p. 99). However, effective cost estimations can be difficult in the early phases of a project as information is limited regarding construction costs.

Improper cost estimations and the costs of materials may dramatically increase beyond what was initially planned. Most recently demonstrated in military shipbuilding was the material cost growth of the LPD 17, SSN 775, and CVN 76. The "LPD 17 experienced over a 100% growth in material costs, 70% of the material cost increases were costs for subcontracts to support the design of the lead ship" (Francis, 2005, p. 13). A government contractor’s use of limited or single-source suppliers for extremely specialized and distinctive materials have made shipbuilding materials highly susceptible to price gouging. Additionally, the “low rate of ship production has affected the stability of the supplier base—some businesses have closed or merged, leading to reduced competition for the services they once produced and that may be a cause of higher prices” (Francis, 2005, p. 15).

Table 7. Examples of Differences in Material Costs between Types of Shipbuilders. Adapted from Deschamps (2009).

Type	Multiplier
Combatants (Large)	1.210
Dual-Use Non-combatants (Large)	1.140
Generic U.S. Modern Commercial (Large)	1.000
Generic U.S. Modern Commercial (Mid-Size)	1.000
US Mid-Tiered	1.000
Northern European (Large)	0.850
South Korean (Large)	0.720

Depending on the type of contract and type of ship being produced, material cost multipliers, demonstrated in Table 7, can affect the overall price. The material multiplier results in higher priced goods depending on the type of ship or location of build. “Mil-Spec materials are regarded as being of a higher standard, with added shock protection. More significantly, vendors and suppliers will increase their prices to cover their added costs to provide the usually required military MIL-SPEC documentation on their products. Foreign shipbuilders often enjoy lower material prices due to greater backlogs and higher levels of purchasing power” (Deschamps & Greenwell, 2009, p. 7). These price differences are demonstrated in Table 8 with varying prices based on geography.

Table 8. Latest Global Steel Prices. Adapted from MEPS (2020).

Country	Hot Rolled Plate Steel Price (Jan 2020)
Europe	533 Euros per ton ($626.47)
USA	740 U.S. dollars per ton
Nordic	556 Euros per ton ($653.53)
Asia Prices	587 USD per ton

E. LABOR COSTS

It is important to find alternative methods for reducing costs as seen by diminishing procurement quantities and overall reduced ship numbers affected by annual cost growth that exceeds the rate of inflation.

Table 9. Labor as Percentage of End Cost by Ship Type. Adapted from Arena (2006).

Ship Type	Labor % of End Cost
Nuclear aircraft carrier	51
Amphibious ship	47
Attack submarine	39
Surface combatant	32

"It is generally accepted that the cost of labor reaches half the construction cost of the vessel's hull, depending on the complexity and type of vessel" (Leal, 2017, p. 4). As demonstrated by Table 9, warship labor costs contribute to a significant portion of the end cost and an area that would benefit significantly from reduced labor rates. The construction of a warship "steel hull, the costs are divided into ¼ for the material (steel) purchase and ¾ in labor" (Leal, 2017, p. 4).

Labor hour increases from design changes and lack of skilled labor for the eight case study ships demonstrated in the GAO investigation "ranged from 33 to 105%, for a total of 34 million extra labor hours and $1.3 billion" (Francis, 2005, p. 11). "Shipbuilders for the LPD 17 and CVN 76 each needed 8 million additional labor hours," with the LPD 17 reaching an additional $284 million" (Francis, 2005, p. 11). While the "labor cost as a percent of total cost growth was the greatest for DDG 91 that amounted to 105%" (Francis, 2005, p. 11). With the diminishing shipbuilding industrial base, a lack of skilled workers to complete the complex tasks, and the experience required to efficiently carry them out has driven the price of labor hour costs. Additionally, material delivery delays contributed to the increase in labor expenses resulting in increased final costs and deadline extensions.

Table 10. Relative Labor Costs Based on GDP per Capita. Adapted from The U.S. Office of Personnel Management (2012); Country Economy (2020).

Countries	Population	Annual GDP (M$)	GDP/ capita ($)	GDP/ Hour ($/hour)
Romania	19,317,984	250,026	12,943	6.222596154
Italy	60,244,639	2,001,290	33,219	15.97067308
France	67,098,824	2,715,580	40,471	19.45721154
United Kingdom	67,025,542	2,824,850	42,146	20.2625
Germany	83,166,711	3,845,718	46,241	22.23125
Netherlands	17,407,585	907,072	52,108	25.05192308
United States	327,352,000	21,433,200	65,458	31.47019231

Table 10 depicts the major European shipbuilding nations ordered from lowest to highest based on GDP per capita. GDP is a measure of the value of goods and services produced in a country. GDP per capita is a measure of GDP per the population within a country, giving a measure of a country's economic prosperity. The Office of Personnel Management estimates that the average number of hours worked by full-time employees annually is 2,080 hours per year. By dividing GDP per capita by 2,080 hours, GDP per hour can be determined to compare the cost of labor between each NATO nation. Table 10 shows that among the leading NATO shipbuilding nations, labor is most costly in the United States and least expensive in Romania. It shows that labor in Italy is nearly half as costly as the United States with a GDP per hour value of about $16.00/hour compared to the United States with a GDP per hour of about $31.50/hour. The data also shows that nations like Germany and the Netherlands have GDP per hour more closely valued to that of The United States with GDP per hour values of $22.23/hour and $25.05/hour respectively. This data shows that labor costs between The United Kingdom, Germany, and the Netherlands are fairly comparable. It also shows the labor from Italy and Romania is significantly less costly than that of the other NATO nations. Finally, this data shows that labor from any NATO ally should be less costly than that of the United States.

F. SHIP DESIGN AND MODULARITY

There is extensive research on the benefits of modular ship design to save costs and time through various methods. Analyzing modular outfitting concepts are utilized in today’s shipyards, with the goal of optimizing the shipbuilding production process while decreasing costs and increasing competitiveness without utilizing large sums of capital investments. The differing methods in shipbuilding by the commercial and governmental sectors have led to a declining base negatively affecting the ability of the Navy to reach demands. Many problems within the Navy stem from the early stages of development and contracting resulting in long-term consequences.

Within the commercial shipbuilding industry, delivering products promptly and within budget is imperative. To do so, they ensure all aspects of design are executed as planned and don’t begin until all critical milestones, product model, and knowledge is attained. A full understanding of the effort needed to design and construct the ship is reached before signing a contract, to enable the shipbuilder to agree on fixed prices, delivery date, and performance parameters. To best minimize risk, designers reuse previous designs to the best extent possible and utilize mature technologies. To ensure a clear line of communication and expectation, buyers maintain a presence throughout the shipbuilding process and that the ship meets quality expectations. The commercial model succeeds due to its discipline in maintaining profitability.

The Navy would greatly benefit from the use of these practices as they are over-ambitious with requirements and developmental equipment unable to meet the needed capacity. It is common practice within naval shipbuilding to start construction before finalization of designs and changes due to experimental technology led to compounding consequences of out of sequence work and rework. Experimental technology requires a full understanding of the design and typically results in cost and time overruns, which must be negotiated within the contract. The Navy takes on almost all of the financial risk by utilizing cost-reimbursable contracts rather than fixed-prices. These inflated costs of building naval vessels under a constrained budget result in fewer ships and higher long term operating expenses. The Navy's continued habit of introducing new technologies at limited volumes, disregarding shipyard competition, and obtaining insufficient expertise has produced high-risk practices (Francis, 2009).

Part of the construction design includes non-recurring engineering (NRE) which is a one-time cost to develop, design, or manufacture a new product that includes setup costs. The non-recurring costs, for example in Figure 5, may also include research, preliminary and contract design, detail production engineering, and production planning. These expenses can be distributed throughout the contract for each acquired ship but are typically recognized in the lead ship cost. Within the government ship acquisition contracts, which include non-recurring costs, they are generally higher than for commercial ship programs. "Combatant surface vessels incur even higher non-recurring costs between 100% to 200%, depending on the complexity of the ship design and the number of ships being built that necessitates more engineering efforts to improve down-stream construction costs and delivery schedules" (Deschamps & Greenwell, 2009, p. 15).

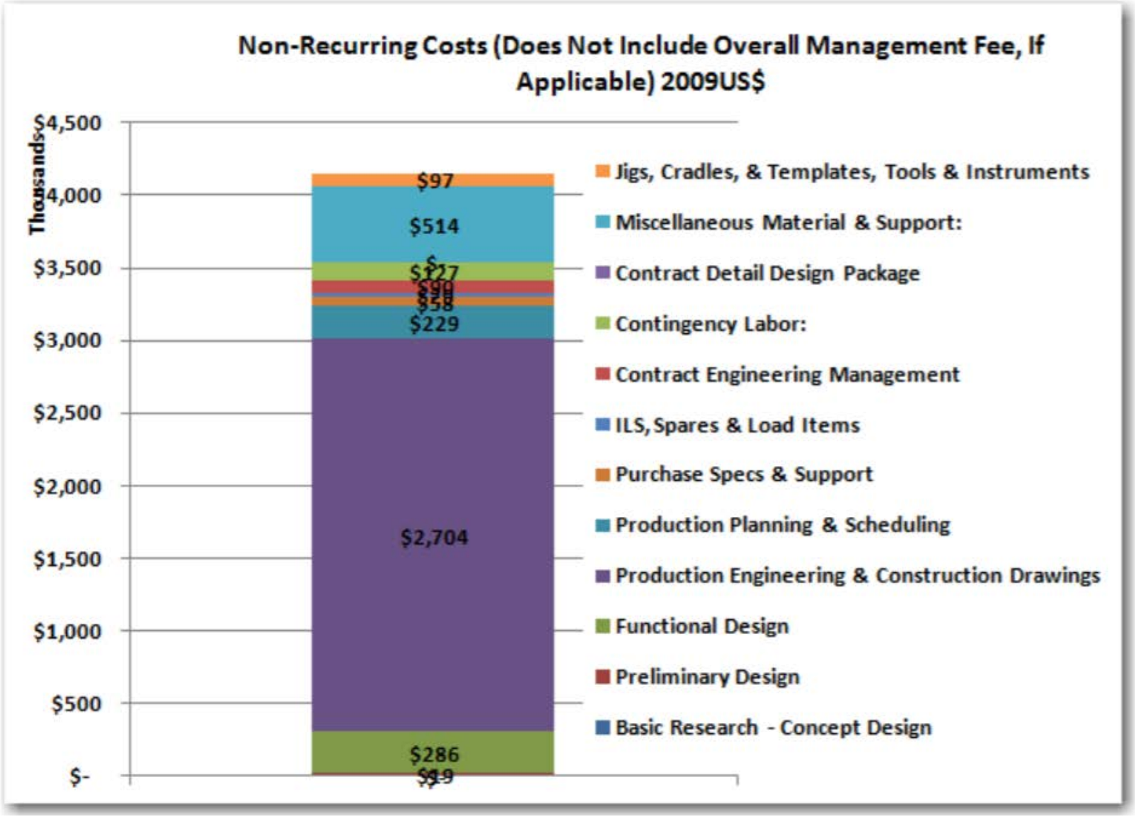

Figure 5. Work Breakdown of Non-Recurring Cost Efforts. Source: Deschamps (2009).

Table 11 portrays the emphasis on the importance of a proper and mature design before construction beginning. "It is estimated that early-stage design decisions drive 75% or more of ship construction and life cycle cost, so design for maintenance and other energy-efficient design initiatives can significantly reduce the cradle to grave cost impacts to ship owners" (Dlugokecki & Hepinstall, 2014, p. 31).

Table 11. Building Stage's Impact on Total Cost. Adapted from Michalski (2004).

Building stage	Cost of the stage	Impact on total building costs
Preliminary design	3%	60%
Other design stages	7%	25%
Ship production	90%	15%

As a design project progresses and more cost information is gathered, contractors' uncertainty of estimates decreases.

> The estimation shows that the design stage, having itself approximately 10 % share in the total building costs, determines 85 % of those costs. Expenses on the design quality—proper choice of the ship's main parameters, production technology, structural materials, equipment types etc.—have a significant impact both on the shipyard's and owner's economic effects. (Michalski, 2004)

By utilizing mature technology and designs, ship manufacturers would be able to cut costs as most of the cost risk is set at the overall acquisition.

If the modularization of shipbuilding can be adopted by the military, there is room for cost savings while also maintaining national security. Figure 6 demonstrates those potential cost savings to capitalize on specialization and overlapping manufacturing timelines. Many of the phases can be kept at the unclassified level and outsourced for non-technical components.

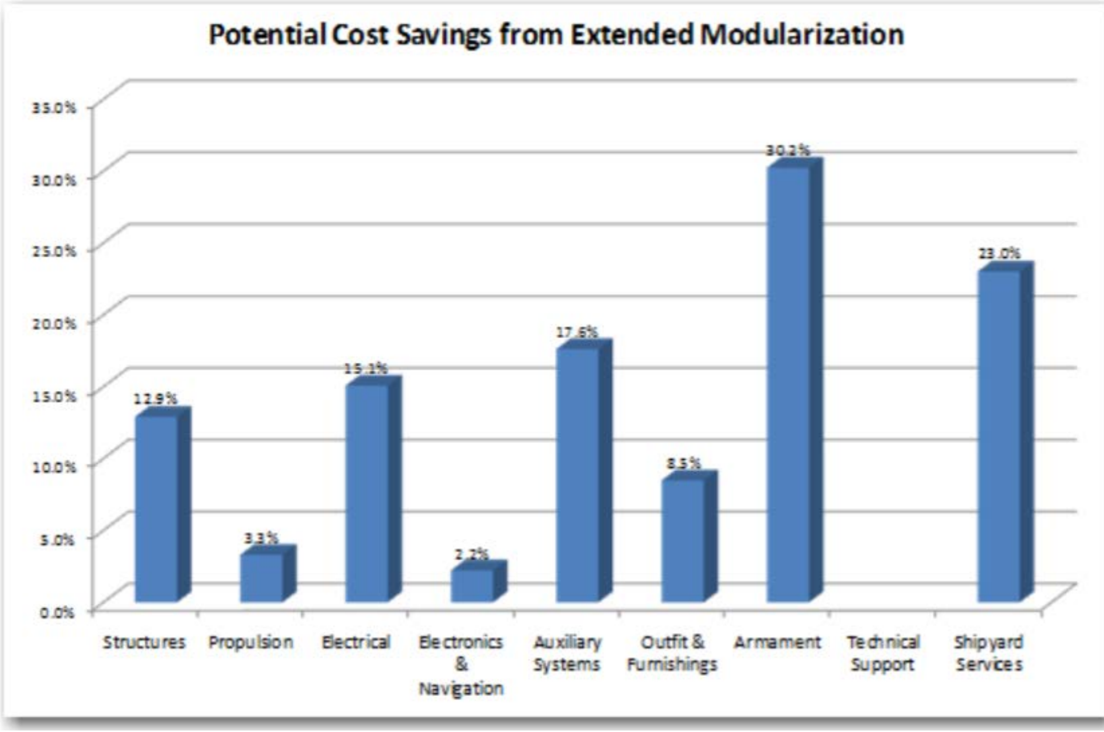

Figure 6. Potential Cost Savings from Extended Modularization. Source: Deschamps (2009).

G. TARIFFS AND EXPORT COSTS

In general tariffs and export costs are transitory and minor in scale with nations imposing equal retaliatory taxes and fees negating the difference in cost between nations. There are three major exceptions to this rule regarding to steel and aluminum tariffs over the past twenty years. These exceptions include the 2002 United States Steel Tariff, and the 2018 and 2020 Trump Administration National Security Tariffs. For the purposes of our analysis, tariffs and export costs will be ignored due to the shifting and retaliatory nature of the imposed taxes, but these three exceptions will be addressed for awareness.

In March of 2002, The United States imposed steel tariffs ranging from 8%–30% on all steel imports (Tran, 2003). These tariffs were in response to a group of analyses that determined the U.S. steel industry was suffering due to an increase in steel imports. The only two nations initially excluded were Canada and Mexico and the measures were intended to remain in place until 2005 (Tran, 2003). These tariffs were met with strong international condemnation particularly from NATO and EU member states and were eventually found unlawful by the World Trade Organization and lifted in December of 2003(Becker, 2003).

In June 2018, the United States imposed a global tariff of 25% on steel and 10% on aluminum (Wollenhaupt, 2020). These tariffs were imposed under section 232 of the Trade Expansion Act of 1962 (Republican Policy Committee, 2018). These tariffs remain in place as of October 2020 as negotiations with NATO states continue. While these tariffs were imposed to strengthen The United States' industrial base and production capability it is unclear if these tariffs have improved or harmed U.S. shipbuilding capability (Wollenhaupt, 2020). An analysis from the Brookings Institute found that there was little way to determine the benefits of these tariffs and stated,

> These tariffs antagonized many of America's closest security partners, particularly Canada, which undermined efforts to cultivate a broader multilateral alliance to challenge China. Moreover, the Trump administration's frequent resources to national security on flimsy grounds will make it more difficult for the U.S. to push back when other countries cloak protectionism in tenuous appeals to national security. (Gertz, 2020, para. 11)

This analysis also illustrated that whatever benefits garnered for U.S. aluminum and steel production was met with increased cost for shipbuilders and decreases in exports due to retaliatory tariffs from foreign nations (Gertz, 2020).

Steel makes up the majority of hull materials but depending on ship class and design, naval vessels can use a substantial amount of aluminum. In August 2020, The United States re-imposed a 10% tariff on Canadian aluminum products after negotiating a cease to the 25% steel and 10% aluminum tariffs imposed by the United States in 2018. Canada responded by placing an equal tariff of 10% on all United States aluminum products (Bown, 2020). Although the United States, Mexico, Canada Agreement, USMCA, had attempted to resolve aluminum trade disputes within North America this recent action has driven the price of aluminum has risen 88% from April 11, 2020, to September 28, 2020 (*Business Insider*, 2020).

H. SHIPBUILDING PRODUCTIVITY

For the last several decades, the standard for shipbuilding productivity has been compensated gross tonnage. Compensated gross tonnage measures the amount of work necessary to complete a vessel of a certain tonnage. By introducing coefficients to account for differing gross tonnage and complexity between vessel types, the compensated gross tonnage system can be used to compare shipbuilding regions and even nations. While there are shortfalls related to this system to include a lack of consideration of the total efficiency of a shipyard such as contractor services, management, marketing, planning, etc., the system remains the standard for comparison. Based on the CGT system of comparison the United States has lagged behind European NATO members in regard to shipyard efficiency. A 1998 study conducted by The Potomac Institute for Policy Studies found that the United States' shipyards were 40% as productive as European shipbuilding counterparts (Hammon & Swetnam, 1998). This trend in poor U.S. performance was echoed by a 2009 productivity analysis conducted by Croatian shipyard Brodosplit that found that the United States' shipyards were one-fifth as productive as Western European shipyards (Cagalj, 2009). Many factors contribute to productivity, but the factors can be broken into two categories: those that affect the input and those that affect the output. The factors that affect the input and contribute most to productivity are management, shipbuilding methods, logistic capability, level of automation, a ratio of production employees to non-production employees, shipyard organization, level of technology within the shipyard, employee expertise and training, and amount of employee absence and working discipline (Cagalj, 2009). Changes in ship design and technologies incorporated within ships will affect the output segment of productivity. For the purposes of this analysis, we will consider the United States' productivity as being 40% that of European NATO nations.

I. GAPS

There are gaps in research that exclude information regarding impacts to the economy and the costs saved and lost by moving shipbuilding overseas to a NATO ally due to the restrictions in place by the Jones Act. The costs saved by switching to a modular platform and quantifying the benefits of different ship designs whether foreign or domestic and at varying locations require more research. Utilizing the cost estimates of designing ships we will calculate the location variation costs coupled with the shipyards to pick the most cost-effective method. Comparing costs attributed to the platform design as well as domestic and overseas shipyard production will be the scope of further research.

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III. ANALYSIS

A. METHODOLOGY

The methodological approach for this analysis will be to conduct a cost-effectiveness analysis of constructing warships within The United States or European NATO partner's shipyards. The use of a procured NATO partner's design or a domestic United States design will also be compared. The areas of comparison will be quantitative data such as material costs, labor costs, shipyard productivity, and other intangible influences on cost-effectiveness through qualitative data. The French and Italian Fincantieri, FREMM, class frigate will be the vessel of comparison and it will be assumed that this design is almost exactly similar to the Constellation class U.S. frigate program procured from Fincantieri.

The limitation imposed by COVID-19 and the closure of NPS and school facilities severely restricted research to online resources. We focused heavily on the most significant expenses in modern shipbuilding which are labor and steel. The single source of steel prices as of January 2020 through the MEPS database by geographic locations is at the base of our material analysis. Information on the wages within the international shipbuilding industry is scarce, which led to the utilization of GDP per capita divided by the average yearly hours worked to produce the productivity and labor rate. The forecast of lost GDP was simplified to disregard possible cascading effects as they become increasingly unquantifiable and that those jobs lost will not remain.

The United States Department of Defense estimates that the Constellation (FFG-62) Class frigate program will cost $1.3 billion for the first ship, $1.1 billion for the second ship, and $940 million for each subsequent ship in 2021 dollars. The Congressional Budgetary Office also conducted a cost estimate of the program and determined an average cost of follow-on units to be $1.2 billion per unit (O'Rourke, 2020). The FREMM class frigates being produced in France cost approximately $790,500,000 per unit (Gautier, 2014). These figures will be used in our analysis comparison to determine the overall cost-effectiveness of manufacturing warships in the United States or Europe. Known data from the manufacturing of the FREMM within the United States and Europe will be compared with expected costs derived from materials, labor, productivity, and other intangibles. Using the FREMM frigate program as the class of ship for comparison will allow for consistent analysis with actual cost differences.

To compare the actual cost of the FREMM program to our anticipated cost based on shipbuilding location and design origin we will use percentages of overall fixed cost from a cost estimation model from SPAR Associates, a shipbuilding planning and production management firm based out of Annapolis, Maryland. Based on the cost estimation data from a 150-meter offshore patrol vessel, we will consider materials to account for 43% of the total cost, labor will account for 20% of the total cost, and non-recurring engineering will account for 15% of the total cost.

Table 12. 150m Off-Shore Patrol Vessel Cost Breakdown. Adapted from Deschamps (2009).

	Labor	Material	Non-Recurring Engineering	Total Cost
Cost ($)	$129,393,147	$275,344,361	$98,557,676	$641,299,563
Percentage of Total (%)	20.18%	42.94%	15.37%	100%

B. DOMESTIC DESIGN BUILT DOMESTICALLY

1. Material Cost Differentiation

Within the production of ships, steel and labor stand out as the highest cost contributors of a final product. According to MEPS, the leading international steel market analysis company, the United States maintains the highest prices per ton of steel as shown in Table 8. At $740 per ton as of January 2020, the United States. was 18.12%, 13.23%, and 26.06% more expensive than our European, Nordic, and Asian counterparts, respectively. With steel being a huge resource required for ship construction, the United States is spending a far higher amount on materials. This, coupled with the cost multiplier of combatant ship materials as demonstrated by Deschamps, the U.S. has the potential for large cost savings of building overseas. Because the Navy tends to be a single-source contractor for materials, they are vulnerable to price gouging, further increasing the price of materials.

2. Labor Cost Differentiation

The U.S. also maintains one of the highest costs of productivity at $31.47 per hour as shown in Table 10. This is 25.63%, 41.56%, 55.33%, 61.72%, 97.06%, and 405.95% higher than in the Netherlands, Germany, U.K., France, Italy, and Romania, respectively. The minimum wage and the demand for skilled laborers have driven up the price per labor hour. By keeping the military shipbuilding sector domestic, of which is 70% reliant on government contracts, the 100,000 direct shipyard labor jobs and the annual $9.8 billion contributed to the GDP would be secure in supporting the U.S. economy (Economic Security, 2020).

a. Shipyard Capacity

The U.S. industry of new construction shipyards is operating beyond capacity by 117–153% and is unable to keep up with the current need (Hooper, 2019). The number of lost contracts due to the limited capacity of the seven current shipyards has driven potential GDP to other countries and allows those company's full control of the prices charged. The Navy's need to maintain ship numbers through the service life extension program (SLEP) and neglecting vital yard cycles have led to higher costs in the long run. Additionally, constant cost overruns and missed deadlines demonstrate the need for the U.S. to shift production overseas.

C. FOREIGN DESIGN BUILT DOMESTICALLY

1. Material Cost Differentiation

As demonstrated in the previous section, steel prices will be significantly more when built within the U.S. and exponentially increasing the overall costs. The Navy contractors will still utilize the same practices and consist of single-source suppliers that further drive up the price of materials.

2. Labor Cost Differentiation

The U.S. maintains one of the highest costs of labor over those countries considered to outsource to, regardless of the ship design.

3. Procured Ship Design

Potential cost savings of procuring a tested and mature foreign design can eliminate a large portion of required R&D. Such an example is seen in the procurement of the new Fincantieri frigate design based on the mature FREMM currently utilized by the French, Italian, Moroccan, and Egyptian navies, as a parent-design approach. “Using the parent-design approach can reduce design time, design cost, and cost, schedule, and technical risk in building the ship” (O’Rourke, 2020, p. 9). As previously discussed, a finalized design and a complete understanding of requirements that account for 10% of the total costs lead to on-time deliveries and lower production costs determining 85% of those costs (Michalski, 2004). A mature design that has been produced numerous times overseas and partnered construction leads to a reduction in learning curve costs. This reduction is cost ranges between 80% and 85% in the shipbuilding sector, meaning a reduction in cost between 15% and 20% with every doubling of production, demonstrated by Figure 7 (Sokri & Ghanmi, 2017). “As operations become more labor-intensive, learning rate increases. Operations that are fully automated have almost no learning, while operations that are entirely manual labor tend to have learning rates around 70%” (Lee, 2014, p. 47).

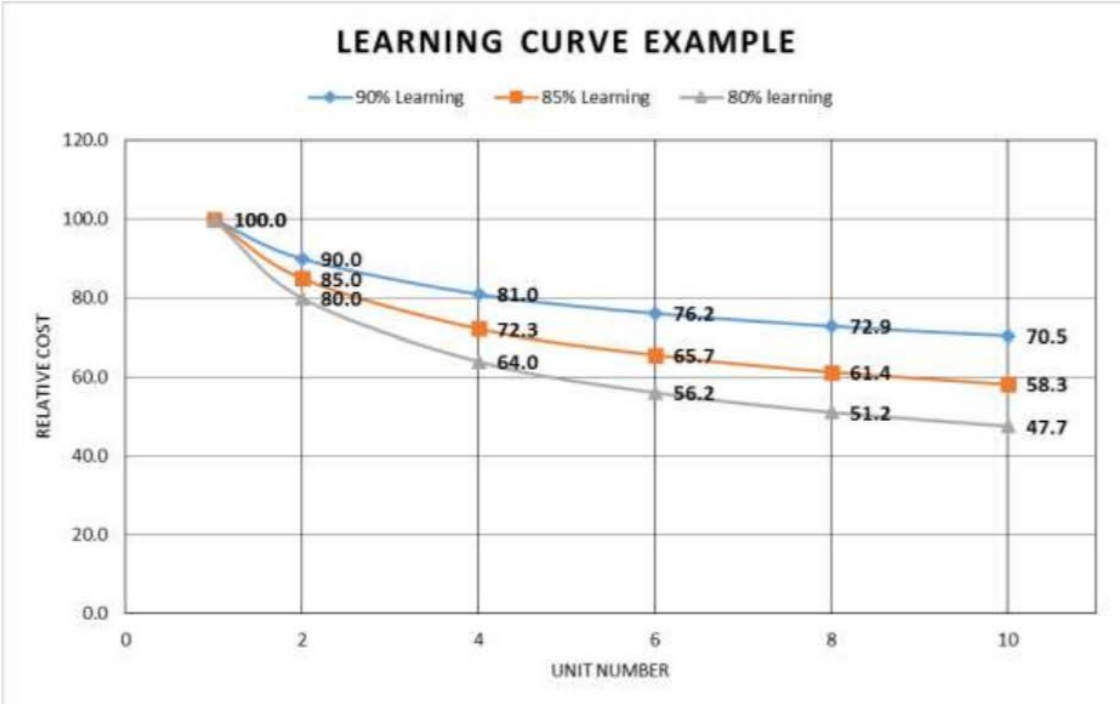

Figure 7. Learning Curve Example. Source: Sokri, (2017).

By utilizing a mature FREMM design the U.S. would be able to capitalize on the European learning curve after the production of 20 units and immediately be able to reduce the relative cost with the aid of European advisors. The percent savings on relative costs can be seen in Figure 7 as the number of units produced double, the costs are reduced by the learning percentage. The shipbuilding industry realizing an approximate 80–85% learning rate after the 20th unit would see about a 50% reduction in relative costs.

D. DOMESTIC DESIGN BUILT OVERSEAS

1. Material Cost Differentiation

European NATO nations enjoy a significantly lower cost for steel. Based on January 2020 estimates from MEPS, steel price in European nations is $626.47 per ton as opposed to $740 per ton in the United States. That equates to 15.34% cheaper steel when manufactured in European NATO nations when compared to the United States. Although steel is not the only material used in the manufacturing of ships it makes up the majority of material cost in the manufacturing process.

2. Labor Cost Differentiation

Labor within European NATO nations is consistently lower than in the United States. The average GDP per hour of labor for European NATO nations was $18.20/hour in 2019 while The United States' GDP per hour of labor was $31.50/hour. Labor cost within European nations varies with Romania having the lowest labor rate of $6.22/hour and the Netherlands has a labor rate of $25.05/hour. This difference in labor cost is significant and would lead to equal levels of labor in any of the European nations being significantly less costly than in The United States. While the cost of manufacturing a United States warship in Europe would also cost The United States significant earnings and jobs, weakening an industry already dependent on military contracts.

a. Shipyard Capacity

Major European shipyards consistently maintain capacity for more projects and could alter build schedules to meet contracts for the United States. European specialization in ferries and cruise ships has enabled major shipyards to maintain both military and domestic build capacity strengthening the industry. Joint projects and collaboration like the FREMM frigate program between the French and Italians enable greater overall capacity between the major European NATO shipyards (Kulkarni, 2015). Increased shipyard capacity means more contracts can be accomplished at more competitive rates. Although European shipyards maintain greater shipyard capacity than the United States, it is unclear how an influx of United States contracts would affect European capacity.

b. Productivity

Productivity within European shipyards has been significantly greater than their United States counterparts. United States shipyards achieve only 40% of the productivity of European NATO nation shipyards. This increased productivity will mean that a ship built in Europe will not only be cheaper but completed more quickly than one built-in the United States. Quicker builds will also mean greater capacity within the shipyards. Although European nations hold a significant advantage compared to United States productivity, shifting production from U.S. shipyards to Europe would mean even less experience for U.S.

workers in a field that has been found to require around eight years of experience to learn the requisite skills and specialization to be 90% efficient (Kulkarni, 2015).

E. FOREIGN DESIGN BUILT OVERSEAS

While most of the criteria analyzed from a U.S. design built overseas there will be a significant shift for costs associated with design and research and development when using a NATO partner design built overseas. As demonstrated with the United States' procurement of Fincantieri's FREMM frigate program, using a tested ship design can save on research and development as well as improve cost saving through the commonality of parts and equipment and manufacturing. Using proven, procured designs reduces construction time by 10% (Michalski, 2004). Design and development as well as on-time delivery accounts for 85% of overall cost and with a robust proven design that reduces the risk of delay (Michalski, 2004).

Table 13. FREMM Comparison U.S. versus European Design and Manufacture

	Labor	Material	Non-Recurring Engineering	Total Cost	Percent Savings
U.S. Build with U.S. Design	$241,479,605	$403,592,509	$401,286,790	$1,196,823,545	00.00%
U.S. Build with European Design	$189,661,065	$403,592,509	$144,463,244	$940,000,000	21.46%
European Build with European Design	$159,496,885	$339,404,126	$121,487,441	$790,500,000	33.95%
European Build with U.S. Design	$143,318,855	$339,404,126	$41,305,730	$710,318,289	40.65%

Table 13 illustrates the cost breakdown based on SPAR cost estimation for a similar vessel. This table illustrates that U.S. labor is 40% more expensive than European labor. This table also illustrates that U.S. materials are 16% more expensive than European's. Finally, both scenarios where a design is procured from outside the manufacturing region show significant cost savings. This data is fairly consistent when compared with our previous analysis of labor and material differences between Europe and the United States.

An analysis earlier in this report found that European steel, the most significant material in warship manufacturing, was around 15% cheaper than steel procured in the U.S. This figure is quite similar to the 16% difference found in the analysis of the real world FREMM case. Analysis from prior in this report found that labor within the United States would be 38% more expensive than French labor. This figure is also similar to the 40% difference in labor cost found from the FREMM case study. Finally, the cost savings column shows the percent difference based on the overall cost of a U.S. designed ship built domestically. The difference between a ship built from European design in Europe compared to a ship built from United States' design in Europe does not reflect how much the United States would pay for either ship as the data is based on the cost of a FREMM frigate the French are paying to build from a European design for use in France. This percent difference of about 7% does appear to illustrate how much less research and development would cost when compared with a ship designed in the U.S. as the difference between a ship built in the U.S. with a U.S. design compared to a ship built in the U.S. of European design is about 21% more expensive when using a U.S. design.

Based on our analysis, the shifting of production overseas would see significant cost savings; however, this would adversely affect the U.S. manufacturing market and GDP. Shifting the production overseas would result in a decline in U.S. GDP for an industry that produces $9.8 billion, of which 70% are government contracts. Shifting warship production overseas would see an approximate $6.86 billion reduction of the $21,433,200,000,000 GDP. This reduction in GDP would not be realized for long as people shift occupations and shipyards pick up new contracts. This would potentially help the commercial industry to combat the restrictions imposed by the Jones Act and the increased prices that it causes.

IV. DISCUSSION

A joint venture is currently being undertaken with the F-35 program and can be compared to a possible future project with the FREMM frigate. The F-35 Lightning II is the United States' fifth generation fighter aircraft program developed by Lockheed Martin (Lockheed Martin, 2020). Three variations of the aircraft were developed for use by the United States Air Force, Marine Corps, and Navy (Lorell & Kennedy, 2013). Australia, Italy, The Netherlands, Denmark, Canada, Norway, Turkey, Japan, and the United Kingdom are all nations currently producing component parts for the F-35 as well as purchasing the platform (Lockheed Martin, 2020). Israel, The Republic of Korea, Singapore, Belgium, and Poland are also slated to purchase the platform from foreign military sales (Lockheed Martin, 2020). There are also two final assemblies and check out manufacturing facilities in Italy and Japan (Lockheed Martin, 2020). This network of partnering nations accounts for 46% of the global economy making the F-35 one of the most significant mutual trade and defense programs in history (Foreign policy). The F-35 program sought to reduce life cycle cost by consolidating research, development, test, and evaluation for all three variants (Lorell & Kennedy, 2013). The program also seeks to reduce life cycle cost through international cooperation, and shared manufacturing and maintenance production. Foreign partnership and sales also improve economies of scale in procurement and operations as well as support, reducing the overall cost of the program (Lorell & Kennedy, 2013). This reduction in cost can already be seen in the F-35's low-rate initial production where LRIP Lot 12 cost a total of $6 billion for 255 aircraft (Tadjeh, 2019). The United States accounted for $3.5 billion and international partners accounted for $2.5 billion of the $6 billion total (Tadjeh, 2019). This example illustrates the cost-saving potential for foreign partnerships. The F-35 program also serves as an example of how international cooperation with military programs can improve interoperability, streamline the supply chain, and reduce overall sustainment costs. All of the core partners of the program produce component parts for the entire program not just for the nation producing the parts (Lockheed Martin, 2020). The widespread use of the platform also makes interoperability more feasible with foreign nations as sensors and communications equipment is shared making joint exercises and engagements more effective. Finally, the F-35 serves as an example of how a shared international military platform can be used as a tool to shape and enforce the United States' foreign agenda. With so many countries contributing as partner nations it makes a significant portion of these nations' defense capability dependent on continued membership in the program (Caverley et al., 2019). Not only does the F-35 provide significant military capability but also boosts a partner nations' infrastructure and economy by producing component parts. This coupled with the large initial purchase price and start-up makes countries who purchase F-35s locked into the program (Caverley et al., 2019). The United States can then use this dependence on the F-35 program to influence foreign actions. The United States used the F-35 program as leverage against both Israel and Turkey to prevent the Israelis from selling drone parts to China and to convince Turkey to cease the purchase of Russian anti-air missile technologies (Caverley et al., 2019). Although Turkey has not agreed to cease the purchase of Russian military equipment the threat serves as a potent tool as the manufacture of F-35 parts is estimated to be a $12 billion industry for Turkey (Caverley et al., 2019). The F-35 is an example of the benefits of international cooperation in military weapons programs and serves as an example for not just future aircraft programs but many other weapon systems including warships.

Based on the previous analysis, the construction of United States warships within NATO member nations in Europe would be significantly less expensive than construction within the United States. While this does not mean major programs should be shifted overseas, opportunities for cost-saving should be explored. It is also clear from our analysis that it is less expensive to purchase and use established ship design rather than incurring the costs of research, development, test, and evaluation. The financial benefits of adopting foreign designs and manufacture are compelling there are also intangible benefits to greater collaboration with European NATO member nations. Greater use of joint international programs would improve interoperability between NATO partners. This commonality of warship platforms would make joint operations easier due to the similarity of communication equipment and capability. This interoperability and shared manufacturing burden would also lead to a reduction in overall life cycle cost as replacement parts and repair capability overseas would be more available. A shared design adds additional benefits of freeing up capacity to conduct in-theater repairs and rapid redeployment of assets. Another intangible benefit from utilizing European NATO nations for the manufacture of United States warships would be to maximize the greatest core competencies of each NATO member state. It cannot be assumed that one nation is the most capable of completing all aspects of warship manufacture. Leveraging the strengths of NATO member states with core competencies would improve the quality of future warships. Collaboration with these member nations could also improve the United States' ability to become more productive and effective.

While there are persuasive reasons both tangible and intangible to pursue warship production within Europe there are also significant reasons to maintain warship production within the United States. The loss of GDP and jobs due to shifting warship production overseas has been discussed but beyond the monetary loss, there would be a serious loss to the United States' ability to respond to a major conflict if the shipbuilding industry and infrastructure were weakened. The limited merchant shipbuilding industry within the United States means the major shipbuilding firms within the United States are dependent on military contracts to maintain proficiency within their workforce and to remain solvent. A shift of production overseas could leave the United States without the industrial complex to meet the demand of major conflict with a peer competitor if necessary. Keeping assets vital to national security such as the production of nuclear-powered ships domestically could reduce this concern of losing all proficiency. There are also compelling reasons to incur the cost of RDT&E to maintain a technological edge over both adversaries and allies. The F-35 program serves as an example of how partnering and selling next-generation military technology with friendly nations creates many of the same benefits as adopting partner designs but enables The United States to use these enormously expensive and lucrative military programs as diplomatic leverage. By holding the keys to other nations' defense, it forces their cooperation with the United States aims and creates great economic opportunity for the United States.

The United States could save costs by shifting some production of warships and United States Navy projects overseas to NATO member states. The best practice would be to embrace further collaboration with NATO members and shift certain manufacturing and RDT&E overseas but still maintain a significant portion of manufacturing and design within the United States. Leaving the installation of combat systems equipment and other classified gear to be done domestically could solve the issue of some of the national security concerns. Foreign collaboration would be particularly enticing for smaller programs like offshore supply vessels and logistics type ships where the United States does not intend to build many ships of each class it would be beneficial to benefit from the cost savings of overseas design and manufacture as the need for next-generation technology is unnecessary. Programs like the Constellation Class also serve as an example of how the United States could purchase foreign design and enhance its capability with United States' combat systems and technology but save cost on the hull design. The development and manufacture of major programs particularly at the strategic level should be maintained within the United States but sake and manufacture with allies should be stressed to take advantage of cost savings and potential for diplomatic leverage.

V. CONCLUSION

The United States must maintain and support domestic shipbuilding and research and development. Next-generation capability is developed and built in the United States and must be supported to continue. However, certain realities must also be accepted. The United States produces warships at a greater cost than its fellow European NATO member states. Both material and labor are more expensive in the United States than in European NATO member states. The United States is also less productive and maintains a lower capacity to produce warships. This analysis provides reasonable evidence to shift select projects of warship production overseas, but this process must be done in a balanced way with agreements and programs that maximize the cost-saving benefit of overseas production while allowing the United States to continue to lead the way in next-generation military assets. The United States can engage in foreign NATO member partnerships while building to meet the capacity requirements of an expanded fleet. It is paramount that the United States maintain the ability to build ships when needed and the current limited shipbuilding capacity means pursuing foreign construction and partnership to meet the increased demand for warships. Shifting certain programs overseas would allow the United States to meet production expectations and benefit domestic shipyards through sharing of best practices and expertise. European shipyards are more productive and produce ships at lower costs. The United States should pursue partnerships with European shipyards to improve industrial practices and learn how to improve United States shipyard productivity. The United States' goal to increase its fleet to 355 or 500 ships in the coming decades gives the U.S. an opportunity to improve warship procurement practices. Greater collaboration with NATO member states will not only strengthen the alliance and our ability to operate but also save costs for the United States and improve domestic shipbuilding proficiency and capacity. The FREMM and Constellation Class serve as an example of potential shared effort to maximize cost-saving and enhance NATO capability. The F-35 program also serves as an example of how joint international partnerships place the United States at the center of global defense and military trade. The United States must shift its focus to great power competition and act to maximize the effectiveness of every dollar spent to win a potential near pear competition. This shift in focus must also ensure the alliances that serve as the foundation for the established international order remain strong. Further partnership with European NATO member states will benefit the United States financially, but, more importantly, it will improve the United States’ ability to meet production requirements.

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