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Revamping Shipbuilding Capabilities in the United States: A Catalyst to Make America Great Again

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Abstract

This paper examines the current state of the U.S. shipbuilding industry, highlighting its historical decline and the challenges it faces amidst global competition and fluctuating naval demands. Despite its economic significance, contributing substantially to jobs, labor income, and GDP through direct, indirect, and induced effects evidenced by 107,180 direct jobs and a $12.2 billion GDP contribution in 2019, the industry has received limited government stimulus. The study contrasts the U.S. situation with shipbuilding practices in leading nations like Japan, China, and Korea, where government support and large conglomerates play significant roles. Recognizing the critical importance of a robust shipbuilding base for both economic prosperity and national security, particularly for the U.S. Navy, the paper proposes leveraging Industry 4.0 technologies to revamp the sector. Specifically Three-Dimensional Laser Scanning (3DLS), Additive Manufacturing (AM), Product Life-cycle Management (PLM) and the integration of intelligent ship (i-Ship)—to revamp the U.S. shipbuilding industry. Preliminary findings suggest substantial cost savings and increased value can be achieved through the adoption of these commercially available technologies, offering a pathway to revitalize the sector, support naval modernization goals (a 335-ship fleet), and contribute to broader the U.S. economic growth. The analysis suggests that the strategic adoption of these innovative technologies offers a pathway to revitalize the U.S. shipbuilding industry, aligning it with modern manufacturing practices and bolstering its contribution to the nation's economic and defense infrastructure. Ultimately, suggesting a pathway to rebuild America's maritime strength and economic prosperity.

Keywords

Maritime Technology, Additive Manufacturing, Internet of Ships, Shipbuilding Industry, 3D Laser Scanner, Product Life-Cycle Management, Intelligent Ship Reporting, Internet of Things

1. Introduction

A strong U.S. shipbuilding industry is considered an essential national attribute by many observers which long pre-date China's ascent. The United States was a peacetime world leader in shipbuilding when ships were made of wood in the early 1800s. During World Wars I and II, the United States built thousands of cargo ships. These were sold to merchant carriers after the wars, including foreign buyers, but were soon replaced by more efficient ships built in foreign yards. In the 1970s, U.S. shipyards were building about 5% of the world's tonnage, equating to 15 - 25 new ships per year. In the 1980s, this fell to around five ships per year, which is the current rate of U.S. shipbuilding (U.S. Maritime Administration, Jones Act fleet listing, acquired by Bollinger Shipyards in 2022).

The termination of the Construction Differential Subsidy program in the 1980s is viewed as being the principal cause of a reduction in the number of ships built in the 1980s. This program was intended to provide ships to U.S. owners at the world price. Still existing is a federal loan guarantee program [1] and tax shelters for new ship construction [1]. Also, the Jones Act of 1920 requires that all vessels used in domestic commerce (not foreign trade) be U.S.-built. This requires ship assembly in the United States, although some components, such as the engines, can be imported. The NASSCO shipyard primarily relies on Navy shipbuilding for revenue. Keppel AmFELS is a new builder of container ships, with deliveries in 2022 and 2023, but it has been a longtime builder of offshore oil rigs. Compared with U.S. shipyards that build large vessels, there are many more U.S. shipyards that build smaller vessels such as tugs and barges; supply vessels for offshore oil, gas, and wind development; and tour boats and ferries. Although these yards support shipyard workforce skills, they lack the infrastructure (e.g., larger dry docks, deeper channels) needed to construct large oceangoing ships. Up until 2018, Philly Shipyard built only commercial vessels, but, running out of orders and facing closure, it pursued and was awarded the construction of five maritime academy training ships funded by the federal government. Despite those orders and subsequent commercial orders, the shipyard continues to operate at a loss.

In addition, overcapacity plagues the shipbuilding sector, though the number of active shipyards in 2022 was 301 compared with a peak of 699 in 2007. Current worldwide shipyard capacity is about 1200 - 1300 ships per year compared with about 2000 ships per year between 2005 and 2010. The three largest shipbuilding firms in China, Korea, and Japan (nine firms in total) account for 75% of world shipbuilding capacity. In 2022, the European Commission scuttled merger plans between Korean shipbuilders Hyundai and Daewoo on the grounds that such plans would create a monopoly for LNG tanker construction.

Despite consolidation, even the most successful shipbuilding firms in Korea and Japan often operate at a loss. According to an annual market review, ship sale prices seldom exceed their building costs. Korean and Japanese shipbuilders are traditionally part of large manufacturing and financial conglomerates (e.g., Samsung, Hyundai, Mitsubishi, Kawasaki) where other profitable segments can help weather the poor profitability of their shipbuilding sector. Even so, Korean shipbuilders have repeatedly required large government bailouts, which have prompted World Trade Organization disputes from Japan and Europe. In China, 36 of the 100 largest shipyards are owned by the national government, 10 are owned by local governments, and 54 are privately owned. The government-owned yards accounted for 64% of ship tonnage built in China in 2021. In the 1990s, an effort to end shipbuilding subsidies worldwide through an Organisation for Economic Co-operation and Development (OECD) agreement was not ratified by the United States [2]. A subsequent attempt initiated in 2002 was abandoned in 2010, but the OECD continues to track subsidy developments.

Further, the world's oceans are critical to U.S. military operatives. Indeed, every significant U.S. military engagement in the 20th century has included ocean transportation of U.S. military forces. The oceans that provide barriers to foreign threats also make deployment of American forces abroad more difficult. But while the United States has developed and deployed the largest and most technically advanced naval forces to guard its approaches and to project U.S. military power; in the post-World War II period, foreign-owned and foreign-built ships have provided most of the nation's ocean transportation The U.S. Naval shipbuilding industry has been in decline since the mid-19th century, when except for wartime production, it peaked.

Over the years, the U.S. government has enacted many laws designed to retain shipbuilding capabilities. For example, laws passed in the late 19th and early 20th centuries granted a monopoly to U.S. shipyards to build ships for trade between U.S. ports. A 1936 law authorized a direct subsidy to shipyards building vessels for U.S. foreign trade, and U.S. naval construction, repair, and overhaul work has largely been reserved for domestic yards.

Nonetheless, many argue that there is less long-term government support for shipbuilding than for competing transportation technologies such as aviation concern about the health of the entire shipbuilding base grew, however, as fierce global competition and a worldwide slump in shipbuilding reduced American commercial large-ship construction to zero. This situation was compounded by the reevaluation of naval requirements and the subsequent reduction in naval shipbuilding as a result of the end of the Cold War. By the end of the 1980s, the President Bush Administration had concluded that "Navy ship-work alone will not sustain the U.S. Shipbuilding Industrial Base" [3].

Expected reductions in naval forces make it even more difficult for Navy work alone to maintain a viable U.S. shipbuilding industry. Critics argue that a strategy focused solely on Navy shipbuilding can neither provide the Navy with affordable ships, nor provide the basis for rapid expansion of naval construction if such an expansion is needed in the future. [4]. This case study considers the potentials of revamping the shipbuilding industry as a catalyst to rebuild America's greatness. The study briefly outlines the current structure and condition of the U.S. shipbuilding industry, the economic importance of the industry in the US economy, condition and retrogressive pattern of naval shipbuilding base. It discusses the common practices in shipbuilding industry among the world leaders in the industry basically Japan, China and Korea. Finally, it considers integrating factors that favors redesigning and revamping in shipbuilding within the US introducing industry 4.0.

2. Literature Review

2.1. The Contribution of Shipbuilding Industry to the Us Economy

The United States is, after all, a maritime nation, is one of the world's largest trading nations, and has the world's largest single national economy. Many of the nation's goods are shipped by sea. In 2008 and 2009, the United States' economy struggled with what has widely been described as "the worst economic crisis since the Great Depression." Specifically, the national economic data show a reduction of 1.7% in real gross domestic product (GDP), measured in constant 2005 dollars, since the beginning of calendar year 2008 [5]. Although this contraction may seem slight, this is the first six-quarter period since 1982 that the national GDP growth has been negative. In a series of efforts to mitigate drastic economic decline, the U.S. Congress passed a $700 billion Troubled Asset Relief Program (TARP) package in October 2008, followed by the $787 billion *American Recovery and Reinvestment Act (ARRA)* on February 13, 2009 [5], of the initial TARP package, about $550 billion has been committed to various financial firms, banks, and institutions throughout the country; so far, $70.1 billion has been returned to the Treasury [6]. The Federal Reserve and the White House continue to seek proper locations for depositing large sums of federal dollars as a means of ensuring continued, consistent recovery of our national economic forecasts. As recently as December 8, 2009, the *New York Times* featured a front-page article in which White House economist Jared Bernstein suggested that the administration is considering an additional $150 billion in stimulus spending, of which $50 billion could be invested "in infrastructure projects alone such as roads, bridges, and water projects" [7]. Additionally, the Office of Management and Budget (OMB) has stated that President Obama believes "we need to rebuild and retrofit America for the demands of the twenty-first century 21st Century" [8].

Furthermore, in a letter to the Senate Majority Leader dated February 2009, the Director of the OMB stated that this rebuilding and retrofitting will "entail repairing and modernizing roads and mass transit options across the country" [8]. Clearly, national leaders are convinced that boosting federal spending is one of the best tools for ensuring that America's $14.3 trillion economy remains healthy and growing at a stable, sustainable pace. The questions now being discussed in various offices and conference rooms throughout Washington, DC, and the country as a whole include robust debates about where to invest these funds. What effects will a $1 trillion health care package have on our weakened economy? Where are the benefits of the *American Recovery and Reinvestment Act;* where have they been manifested? The executive branch claims to track every dollar spent under this $787 billion umbrella, but how is that spending really benefiting the economy? Other, perhaps equally important, questions exist for industries and sectors yet to benefit from federal spending packages and stimulus measures—what *could* investments in those sectors be doing to improve the economy?

With a $20 trillion debt threatening generations of American prosperity [9], our Federal budget must spend every dollar effectively, efficiently, and in ways that make a demonstrable, difference for America's economy. One important industry that has not received direct funding from government intervention in the current recession has been the U.S. shipbuilding sector. A search for "shipbuilding" at the federal government's Web site, which is designed to provide transparency to American citizens, reveals that a mere $132,000 of the $787 billion ARRA package has been allocated to a company called Horizon Shipbuilding in Alabama [5]. This $132,000 payment from the Department of Transportation is the only evidence of *ARRA* funding for shipbuilding; thus, not even 1/10 of 1% of the *American Recovery and Reinvestment Act* has been invested in shipbuilding companies.

Those with an interest in the U.S. shipbuilding industry believe that their particular sector of manufacturing has a special ability to provide economic stimulus for national decision makers and taxpayers alike. As politicians seek to stimulate and sustain U.S. economic growth, they hope to create or maintain jobs, expand national gross domestic product, and provide a lasting resource for future economic potential; investments in shipbuilding and taking advantage of the technological advancement to improve the capabilities of the ships may accomplish all three goals through the direct impact, indirect impact and induced impact on the US economy, as this section seeks to demonstrate.

In 2019, the U.S. private shipbuilding and repairing industry directly provided 107,180 jobs (see **Figure 1**), $9.9 billion in labor income, and $12.2 billion in gross domestic product, or GDP, to the national economy (see **Figure 2**). Including direct, indirect, and induced impacts, on a nationwide basis, total economic activity associated with the industry reached 393,390 jobs, $28.1 billion of labor income, and $42.4 billion in GDP in 2019.

Considering the indirect and induced impacts, each direct job in the U.S. private shipbuilding and repairing industry is associated with another 2.67 jobs in other parts of the U.S. economy; each dollar of direct labor income and GDP in the U.S. private shipbuilding and repairing industry is associated with another $1.82 in labor income and $2.48 in GDP, respectively, in other parts of the U.S. economy.

The importance of the industry is not limited to the direct output and employment it generates (*i.e.*, "direct impact"). Companies in the shipbuilding and repairing industry purchase inputs from other domestic industries, contributing to economic activity in those sectors (*i.e.*, "indirect" impact). Employees spend their incomes, helping to support the local and national economies (*i.e.*, "induced" impact). Thus, the economic importance of the U.S. private shipbuilding and repairing industry includes direct, indirect, and induced effects. Put differently, the report seeks to document what happens in the U.S. private shipbuilding and repairing industry and its relationships to the broader economy.

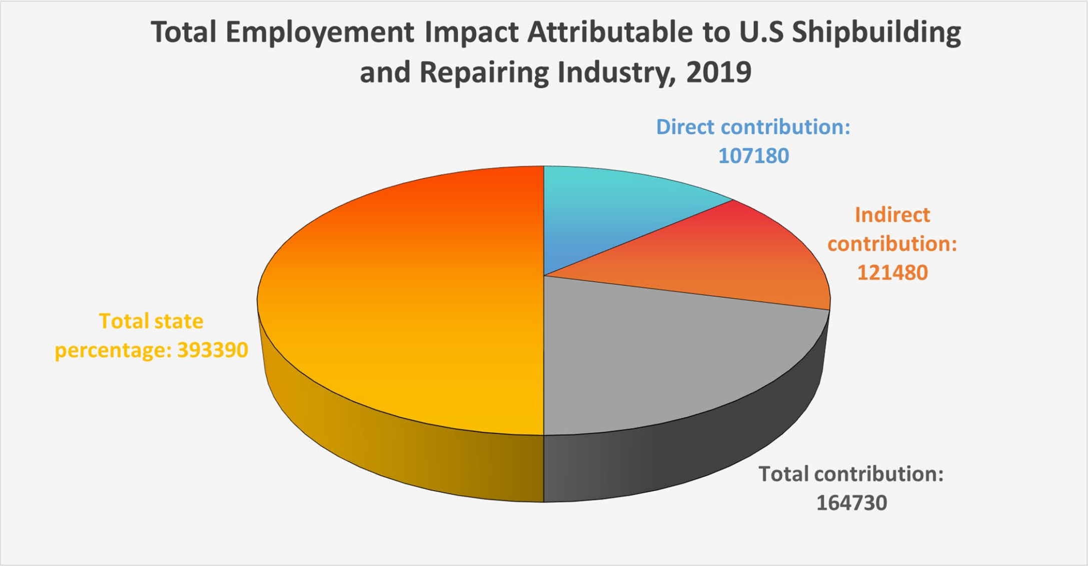


Figure 1. A chart showing the total employment impact attributed to the U.S private shipbuilding and repairing industries.

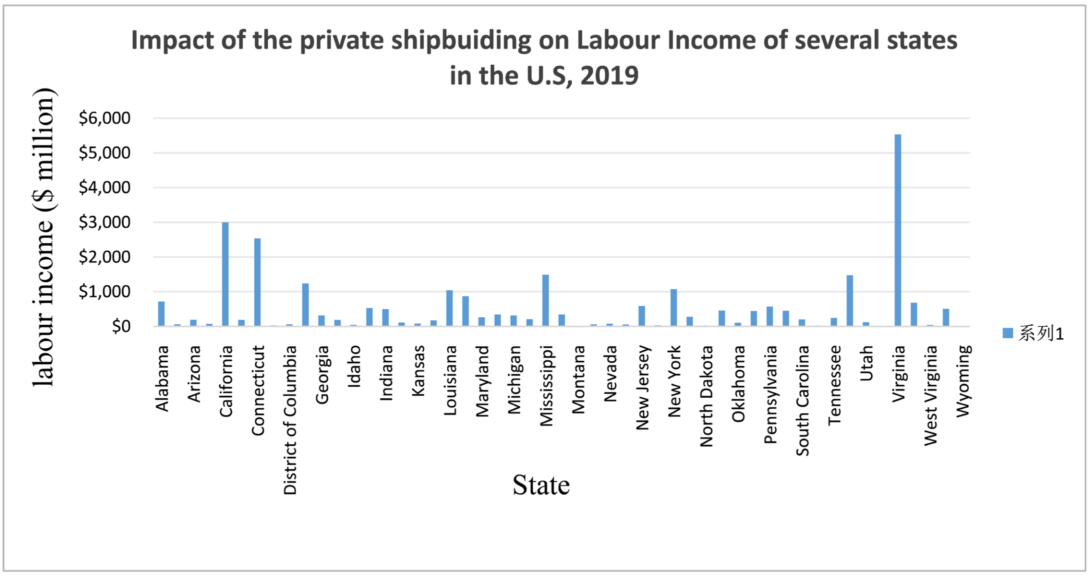


Figure 2. A chart showing the total labor income and GDP impacts attributable to the U.S shipbuilding and repairing industry.

1) Direct impact is measured as the jobs, labor income, and GDP within the U.S. private shipbuilding and repairing industry.

2) Indirect impact is measured as the jobs, labor income, and GDP occurring throughout the supply chain of the U.S. private shipbuilding and repairing industry. The indirect impact also includes suppliers to the companies providing goods and services to the U.S. private shipbuilding and repairing industry.

3) Induced impact is measured as the jobs, labor income, and GDP resulting from household spending of labor income earned either directly or indirectly from the U.S. private shipbuilding and repairing industry's spending under standard input-output modeling assumptions.

Together these effects demonstrate the private shipbuilding and repairing industry's economic importance and relationship to all sectors of the U.S. economy.

While addressing the congress in 2017 and presenting the 2018 budget, President Donald J. Trump says "…As this Budget returns us to economic prosperity, it will also allow us to fund additional priorities, including infrastructure, student loan reform, and initiatives…"

He added "It is now up to the Congress to act as I pledge my full cooperation in ending the economic malaise that has, for too long, crippled the dreams of our people.

Investing in US shipbuilding sector and redesigning the ships may be one of the new infrastructures that leads America to the path of economic prosperity.

2.2. Significance of Shipbuilding Industry for the Department of Defense (DOD)

Apart from the economic advantage of redesigning and resurrecting the shipbuilding industry in the US, this section discusses the challenges of shipbuilding redesigning, difficulty in the adoption of innovative concepts into shipbuilding and its impact on the national security of the United States of America.

For many decades, the Naval Sea Systems Command (NAVSEA) has had a primary responsibility to translate operator needs into technically achievable ship ideas. Thus, there is an urgent need for NAVSEA to offer a pool of highly skilled, highly motivated ship design engineers to assure the Navy's future ability to develop creative, cost-effective warship designs. However, the Navy's ability to maintain its in-house ship design expertise was jeopardized by a 12-year engineering downsizing at NAVSEA headquarters (SEA 05). NAVSEA had maintained this in-house design expertise since Naval Constructors were dispatched to colleges in Scotland and France to study how to construct modern warships, following a long post-civil war naval slide to near obscurity.

During the 1990s, the number of highly experienced ship design engineers at NAVSEA headquarters dropped substantially, from around 1200 in 1992 to less than 300 in 2005. The adverse implications of this decline prompted a call to action. To help address this negative human capital trend, NAVSEA, the Office of Naval Research (ONR), and the Naval Surface Warfare Center (NSWC) founded the Center for Innovation in Ship Design (CISD) in 2002. In 2006, CISD was charged with creating a Human Capital Strategy (HCS) for Ship Design Acquisition Workforce Improvement. The Ship Design Management HCS will ensure a highly experienced warship design workforce, ensuring NAVSEA keeps its place as the nation's leader in navy ship design. Shortly after the creation of the NSWC, the Government Accountability Office (GAO) wrote a letter to the congress committee 2nd of May 2024 about how the changing maritime threats are pushing the U.S. Navy to increase its pace for designing and delivering new ships. Since 2009, GAO has used leading practices in commercial shipbuilding to evaluate the plans and execution of Navy shipbuilding programs. GAO's numerous recommendations have spurred the Navy action to improve acquisition practices and the use of taxpayer dollars. Yet, the Navy has continued to face persistent challenges in its ability to design and deliver timely, affordable new ships that perform as expected.

Achieving the adoption of innovative concepts into new U.S-NAVY ships during the course of their design has proven to be a difficult task. While innovation itself does not guarantee improvement, it is certain that there will be no improvement without it. If in the past, the U.S-NAVY was able to afford the luxury of being lax about the pace of innovation adoptions, today, in an age of accelerating technological development, it is a luxury that can endanger our freedom. The US-NAVY have the expertise of inventing new technology, but in many instances, compared with many other major world Navies, are quite very slow to adopt innovations, especially in the platform as opposed to the payload side of the warship.

Some notable examples showing how the NAVY have been slow to adopt innovations are seen in the Innovation Adoption of:

1) Roll Stabilizers in the 19th century;

2) Gas Turbines in the early 20th century, as published in the naval engineering journal.

Those who have attempted to measure innovation in large technology based organizations, such as the NAVY, have proposed various correlations such as: percentage of funds spent in the research and development R&D relative to total acquisition expenditure; numbers of patents that the organization applied for; the size of NAVY Laboratories devoted to R&D; and the number of Ph.D.s on the staffs of laboratories as well as other similar surrogate measures. However, the record shows that there is little correlation between any of these factors and the rate of adoption of innovations. Inventions, creativity, experimentation, or the number of patents must not be confused with innovation adoption. What counts is the number of worthwhile innovations adopted—something the Navy has been extremely slow in doing in numerous instances.

Between 1954 and 1974 the Department of Defense (DOD) spent $28.2 billion in private shipyards on direct procurement of ships; and, the Maritime Administration (MARAD) furnished $1.6 billion in the form of subsidies for building commercial ships, in accordance with the Merchant Marine Act of 1936, as amended [5]. The productivity of the shipbuilding industry is of special importance to the Government in relation to these objectives, both in terms of military readiness and the amount of Federal funds payable in the form of construction subsidies.

2.3. Common Practices and Analysis of the Shipbuilding Industry among the Asian Tigers

The shipbuilding sector is crucial to the world economy, as 80% of world trade is conducted by sea. Up to the end of the 1990s, Europe was a leader in all segments of the shipbuilding industry. Since then, China, South Korea, and Japan have dominated the shipbuilding market across the world. Asian shipyards have specialized in producing bulk carriers and container ships, that is, vessels that are relatively simple Technologically The section seeks to analyze the changes taking place in the Asian shipbuilding markets, considering the impact of the crisis in the shipbuilding industry due to the technological innovations and financial impediments.

1) **China**

China's shipbuilding industry transformed from a fragmented sector in the late 1990s, consolidated under the state-run China Shipbuilding Industry Corporation (CSIC) and China State Shipbuilding Corporation (CSSC). These entities handled all aspects of shipbuilding, from modern vessel construction (CSSC) to a vast network of repair, design, and equipment production (CSIC) [10]. The state's unwavering financial support was the bedrock of its global competitiveness.

Post-2000, China's policy aggressively backed its domestic industry. Government intervention directly lowered production costs via subsidized steel and provided low-interest export credits (up to 80%) to ship buyers through key banks. Furthermore, customs duties were waived on imported components, further bolstering the industry.

Fueled by financial support and low production costs, Chinese ships quickly became globally competitive. Between 1998 and 2008, robust government backing propelled China to become a world leader in bulk carriers and container ships. By 2005, China's shipbuilding industry comprised over 2000 companies employing approximately 400,000 people [10].

China's share in global shipbuilding surged from 9% in 2005 to over 24% by 2015, significantly outpacing declines in the European Union, Japan, and South Korea. In terms of sheer volume, China ranked second only to Japan in 2006-2007, commissioning 491 ships in 2006 (vs. Japan's 603) and 459 in 2007 (vs. Japan's 559) [11].

When the 2008-2012 global financial crisis hit the industry hard, the Chinese government responded by subsidizing the scrapping of older, polluting ships and promoting new builds to mitigate the negative impact.

Modern, specialized ship production and efficient, automated shipyards are crucial for global shipbuilding competitiveness [12]. To this end, in 2019, Chinese authorities formed the China Shipbuilding Group (CSG) by merging CSIC and

CSSC, establishing the world's largest shipbuilding enterprise. By late 2019, CSG commanded 310,000 employees and encompassed a full spectrum of academic, production, repair, and industrial capabilities.

CSG's innovative approach enables competition across all shipbuilding sectors, including lucrative cruise liners. SASAC Chairman Hao Peng affirmed CSG's purpose: "to enhance the competitiveness of the domestic shipbuilding industry, promote the development of the national defense technology industry and reform state-owned enterprises" [13]. Critically, this strategic consolidation was made possible by enormous state support, totaling an estimated USD 132 billion in state aid (USD 127 billion from state-owned banks, USD 5 billion in direct subsidies) for Chinese shipbuilding and shipping between 2010 and 2018, with indirect subsidies excluded [14].

2) **South Korea**

Since the mid-2000s, the South Korean shipbuilding industry has consistently maintained its position as the second largest global market shareholder, following only China. This sector exhibits a distinct specialization profile compared to its key competitors. While China and Japan primarily focus on the construction of container ships and bulk carriers, South Korea has strategically concentrated its efforts on the production of higher-value vessels, specifically tankers, gas carriers, and container ships.

South Korea's sustained global competitiveness within the shipbuilding arena can be largely attributed to its pioneering adoption and continuous utilization of advanced modern technologies. This technological leadership has been instrumental in its capacity to export ships globally, a segment in which South Korea remains the preeminent exporter, in contrast to China, which holds the distinction of being the largest producer by volume. The South Korean shipbuilding landscape is notably dominated by three prominent private entities: Hyundai Heavy Industries Co. Ltd., Daewoo Shipbuilding and Marine Engineering Co. Ltd., and Samsung Heavy Industries Co. Ltd., which collectively shape the industry's output and strategic direction.

However, the operations of Korean shipyards were significantly impacted by the global economic crisis that commenced in 2008. This worldwide downturn led to a substantial reduction in the order book for new ships. Data indicates a steep decline in orders from 557 vessels in 2008 to a mere 140 in 2009. While there was a partial recovery to 464 orders in 2010 and 351 in 2011, the trend reversed, falling to 231 in 2012 [11]. This pronounced decrease in demand for South Korean shipbuilding products from 2009 onwards was a direct consequence of the severe financial distress experienced by shipowners, compelling many to either cancel their intended purchases or opt for more cost-effective alternatives available from Chinese shipyards.

3) **Japan**

In the 1990s, Japan's shipbuilding industry held a commanding position in the global market. However, over the first two decades of the 21st century, it lost its leadership status. Despite this, Japan's industry remains substantial, with over 1000 shipyards operating since 2000, most of which are private enterprises. Leading shipbuilders like Imabari Shipbuilding, Tsuneishi Holdings, and Oshima Shipbuilding Company primarily construct bulk carriers, container ships, and chemical tankers. Nonetheless, approximately 700 Japanese shipyards concentrate on the construction and repair of smaller vessels.

A significant challenge for Japanese shipyards has been their comparatively smaller production capacity compared to their counterparts in China and South Korea [15]. This lower capacity, combined with higher production costs in Japan, translates into less competitive pricing and fewer orders for Japanese ships. While Chinese and South Korean shipyards often offer simpler designs, particularly for common vessel types, Japan has historically focused on complex vessels such as passenger ships and gas carriers. This specialization, however, has not been without its drawbacks; for instance, in 2000, Japan's Mitsubishi Heavy Industries shipyard incurred a loss of approximately USD 293 million due to delays in completing two passenger ships, highlighting the financial risks associated with highly specialized and complex projects.

Japan's share in the global shipbuilding market decreased sharply from 27% in 2005 to 13% by 2013. Concurrently, the combined share of Chinese and South Korean yards significantly expanded from 53% to 77% over the same period [16]. In response to these market dynamics, Japanese shipyards initiated strategic efforts to regain competitiveness beginning in 2004. The Ministry of Land, Infrastructure, Transport, and Tourism has actively guided this revitalization, developing and implementing plans early in the 21st century to enhance global market competitiveness. Government policy has included direct support mechanisms, notably export credits, to bolster the industry. These concerted efforts have yielded tangible results: by 2018, Japan successfully maintained its third-place global ranking in terms of its share of the order book for ships, securing a 29.9% global share. This demonstrates a measured recovery and a re-established, albeit reconfigured, competitive presence in the international shipbuilding landscape.

3. Technological Approach to Revamping the Shipbuilding Industry

To effectively and efficiently build and fund the projected larger fleet, the U.S. shipbuilding industry must reduce costs while meeting mission needs by leveraging the full benefits of new technologies. Three-Dimensional Laser Scanning (3DLS), additive manufacturing (AM), and product life-cycle management (PLM) may be able to provide such benefits.

The current work tests this hypothesis by estimating potential cost savings and return on investment (ROI) to assess the impacts of these commercially available technologies on naval and commercial shipbuilding. Results indicate that very large savings and increased value are possible by adopting and using these technologies.

The U.S. Navy seeks to become a battle force of 335 ships over the next 30 years [1], which is an increase from today's battle force of 289 ships. In a report submitted to Congress in February 2018, the Navy's 2019 shipbuilding plan covering fiscal years (FY) 2020 to 2050 forecasts that the plan would cost $106.45 billion through FY 2023, an average of about $21.3 billion per year. With the national debt at over $36.2 trillion as of January 2025, the budget pressures require both the Navy and the private shipbuilding industries to simultaneously pursue cost savings while improving valuable capabilities.

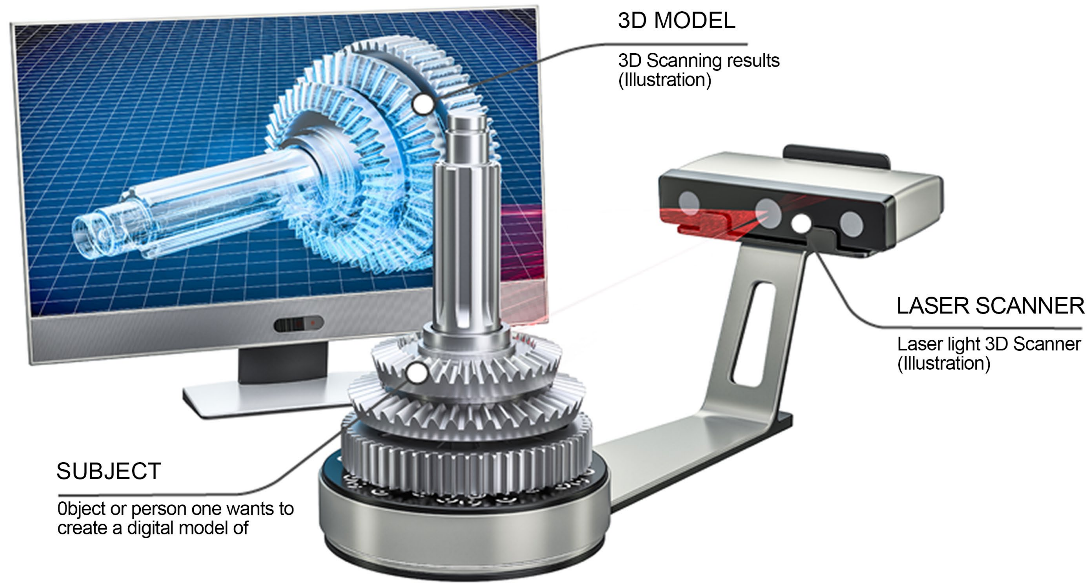
3.1. Innovative and Commercially Available Technologies

Shipbuilding requires numerous types of facilities, large level land areas, and various types of production equipment, all of which must be efficiently planned and integrated. Also, the shipyards need sufficient storage space, complete with lifting equipment, to move and store various sizes, shapes, and types of steel plate, pipe, and structural shapes. Facilities are also needed to provide protective storage for many items used in outfitting ships. The facilities must be capable of moving, handling, and lifting materials and units ranging in weight from several tons to hundreds of tons. To provide for economical and efficient shipbuilding, the facilities need to be arranged to handle material as little as possible and to promote a smooth and even flow of work through the various stages of shipbuilding.

Adopting and using new technologies in shipbuilding is a potentially effective way to meet these goals. Four innovative and commercially available technologies (*i.e.*, Three-Dimensional Laser Scanning [3DLS], additive manufacturing [AM], Product Life-cycle Management [PLM] and intelligent ship [i-Ship]) may generate large savings in shipbuilding industries without degrading capabilities, thereby improving the industries. These four technologies were chosen as the basis for this study based on prior research in the manufacturing sectors [17]-[20].

1. ***Three-Dimensional Laser Scanning***

Laser scanners use infrared laser technology to produce exceedingly detailed three-dimensional images of complex environments and geometries in only a few minutes (as illustrated in **Figure 3**). The resulting images are rendered by software into three-dimensional point clouds that can be used to design improvements, verify construction, and improve other operations. 3DLS technology has been used to achieve significant cost savings, optimize maintenance schedules, increase quality, improve safety, and reduce rework. Commercial applications range from maritime and space applications to manufacturing and production with applications in law enforcement for crime scene documentation, architectural and civil engineering as the basis for Building Information Modeling (BIM), factory and plant maintenance for equipment installation, and surveying to capture and calculate volumes.



Source: https://images.app.goo.gl/S2YAJ7Wa4zUhrY5G6.

Figure 3. A picture of the 3D laser scanner.

The National Shipbuilding Research Program [21] funded two Ship Check Data Capture projects in 2005 and 2006 to develop a process that captures as-built measurement data in digital/electronic format during a ship check. The two projects grew out of a need to process the as-built measurement data into 3D computer-aided design (CAD) models using available commercial-off-the-shelf (COTS) modeling technologies, and to provide a process for the development of 3D CAD models. The FY 2006 follow-on project refined the ship check process to better align it with the U.S. shipbuilding and repair industry using COTS technology. Performance improvement metrics were developed and tracked to compare the "as-is" practice with anticipated project results. Estimated cost savings of 37% and time savings of 39% compared to traditional ship checks using tape measures were realized [21] [22]. The Naval Undersea Warfare Center (NUWC) began using laser scanning to reverse engineer components with complex geometries to enable competitive bidding in 2007. In the past, the Navy did not have sufficient documentation from the original equipment manufacturer (OEM) to competitively procure replacement components, which resulted in purchasing very expensive replacements from the OEM. The Navy saved $250,000 by purchasing parts produced with laser scanning through competitive bidding. In addition, the time required to reverse engineer a typical component, including both measurement and modeling time, was reduced from 100 hours to 42 hours with a laser scanner.

These programs revealed that 3DLS can improve shipbuilding-related operations by reducing or eliminating return visits to sites for missed measurements and by providing more accurate and complete as-built data that can improve design and reduce rework, thereby increasing cost avoidance.

2. *Additive Manufacturing*

Additive Manufacturing (AM) is the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" [23]. It differs radically from subtractive processes (e.g., machining) by building a 3D object by gradually adding successive layers of material (see **Figure 4**). AM fabricates objects directly from 3D CAD models. The 3D model is disaggregated into multiple horizontal layers, each of which is produced by the machine and added to the preceding layers. AM is often referred to as "3D printing.

Very large improvement in manufacturing performance is possible with AM. For example, Lockheed Martin estimates that some complex satellite components can be produced 48 percent cheaper and 43 percent faster with AM, and production costs could be reduced by as much as 80 percent. Boeing has installed environmental control system ducting made by AM for its commercial and military aircraft for many years; tens of thousands of AM parts are flying on 16 different military and commercial production aircraft [24]. Ford Motor Co. uses AM in several areas, including the tooling used to create production parts and to build intake manifold prototypes that can be tested for up to 100,000-mile cycles. With traditional manufacturing methods, it would take 4 months and cost $500,000 to build, while an AM manifold prototype costs $3000 to build over 4 days.

Figure 4. A picture showing the Addictive Manufacturing technology.

Office of Naval Research studies have shown that an AM technology (Electron Beam Direct Manufacturing) process has the potential to reduce per-part manufacturing costs by 35% - 60% compared to costs to manufacture complex-shaped parts with traditional manufacturing approaches (Office of Naval Research, 2016). Product lead time might also be reduced by as much as 80%. The U.S. Army deployed in July 2012 its first mobile 3D printing laboratory in Afghanistan inside a shipping container that is capable of being carried by helicopter.

The Metalworking Center conducted the "Additive Manufacturing for Shipbuilding Applications" project to demonstrate the cost and time benefits of AM to support the construction of Navy platforms. Ingalls Shipbuilding has estimated a minimum acquisition cost savings of $800,000 per year by utilizing AM for the construction of Destroyer Designated Guided (DDG), Landing Helicopter Assault (LHA), and Landing Platform/Dock (LPD) Navy platforms [25].

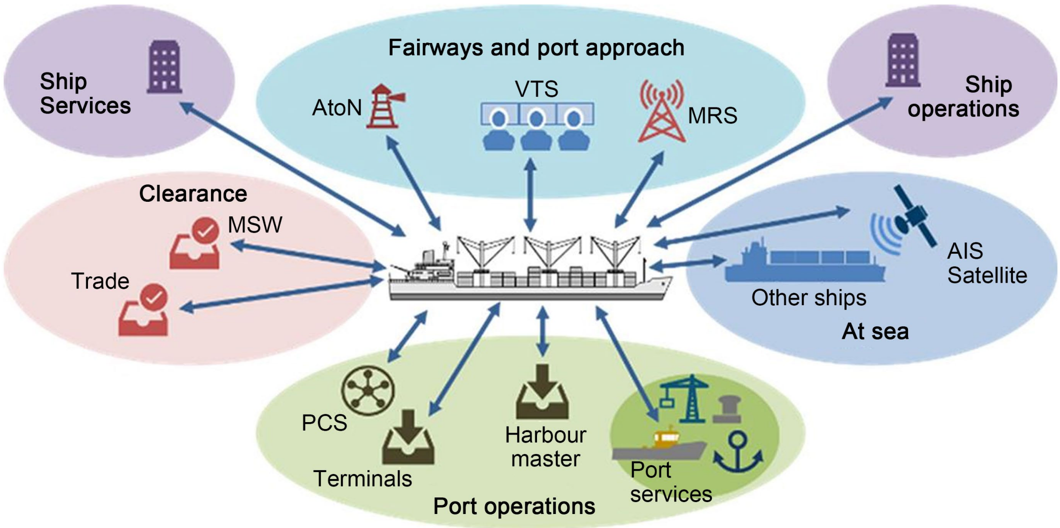
3. *Product Life-cycle Management*

PLM is an "integrated, information-driven approach comprised of people, processes/practices, and technology for all aspects of a product's life, from its design through manufacture, deployment, and maintenance— culminating in the product's removal from service and final disposal [26]. By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of "lean thinking" [27]. PLM has been used by the automotive, aerospace, and other industries that build very large, very complex products and systems (illustrated in **Figure 5**). It was designed to provide stakeholders with current views of every product throughout its life cycle to facilitate decision making and corrective actions, if necessary.

Figure 5. A picture model showing the product life-cycle management.

4. *i-Ship (Intelligent Ship Reporting)*

The intelligent Ship Reporting Gateway (i-Ship) is an innovative software application, enabling ship representatives to fulfil their reporting obligations to European and International maritime and custom authorities. i-Ship can be used to automate reporting formalities in a timely and correct manner taking into account the type of ship and the voyage (as shown in **Figure 6**).



Source: https://images.app.goo.gl/wj3xJo6mUmERPHTF7.

Figure 6. A model displaying the intelligent ship reporting.

Applications of the intelligent ship reporting

Ship Managers: Ship managers introduce voyage information directly using the i-ship web application or via connection to the company's applications. The data introduced may include cargo information.

Cargo Consignors: Cargo consignors introduce cargo consignment data being aware, or not of the specific cargo movements, which are decided by the ship operator. Example of the application of the new technologies/processes based on a real case study, quoting users' reactions if possible and with multiple pictures.

Ship Representatives: Ship masters, agents at a specific port or other authorized users submit port clearance related formalities to maritime Single Windows or related authority systems.

Cargo Representatives: Cargo representatives submit cargo clearance formalities to maritime Single Windows such as ENS, eManifest etc., to Port Systems or to Custom Authorities (e.g. ICS, ECS).

3.2. Introducing the Industry 4.0 as it Affects the Shipbuilding Industry

Industry 4.0 has been defined as "a collective term for technologies and concepts of value chain organization" which draws together Cyber-Physical Systems, the Internet of Things and the Internet of Services, but the Industry 4.0 concept has existed since 1991, since its introduction by Mark Weiser [28]. He described the vision of the future with the term of "Ubiquitous Computing". From that period a lot of the things have become reality, such as smart mobile phones, cars as wheeled computer system, and smart homes.

The first industrial revolution was introduction of water and steam-powered mechanical manufacturing, the second industrial revolution was the implication of electrically-powered mass production; the thirds industrial revolution was introduced to use of electronic and information technologies (IT) to achieve further automation of manufacturing [29]. The Industry 4.0 is based on the Cyber-Physical Systems, it represents the mass customization of the products turned to the wishes of the customer with the implementation of the intelligent, smart and optimal solutions embedded in the products. Industry 4.0 has strong impact on the worldwide industries and the all aspects of the human society including the Maritime sector.

According to the Capgeminis recent report, smart factories as the base of the Industry 4.0 will be adding up to 500 billion dollars in value to the global economy. Also, almost 76% manufacturers in the world already have some level of a smart factory initiative. The main items of the Industry 4.0 applicable in the Maritime Sector and supported industries are:

- Cyber-Physical systems
- Big Data
- Digitization of the Industry
- Internet of Things
- Internet of the Services
- Internet of ships

Almost all major players in shipbuilding industry are preparing themselves for the changes that will come in next 10 to 20 years, and strongly working on their own steps toward fourth industrial revolution. In the history, the industrial revolution usually brings the strong changes in the all aspects of the human society supported by the governments

The Industry 4.0 is strategic initiative and it represents the synonym for the transformation of today factories into Smart Factories which will be capable to overcome the challenges of the product lifecycle, highly customized products and to stay in the race with ubiquitous competitors. The smart products from the Smart Factories are customized, identifiable and know their current status and target state [29]. The whole concept is based on Cyber-Physical Production System (CPPS), Internet of Things, Big Data and Internet of Services and interaction of the real and virtual world [30]. It presents development that changes the overall traditional industries and includes design, technology and innovation cycles which is seen as an important strategy to remain competitive in the future [31]. The smart products from the smart factories will allow the "last minute" changes to the customer requirements. This dynamic business and engineering process enables the production, delivery and flexibility to disruption and failure during production. For the smooth functioning of the concept, it will be important horizontal and vertical integration through across the value chain [29].

3.3. Simulation and Result Using Three Technologies

The system dynamics model to conduct a comprehensive simulation of shipbuilding processing rates, initially focusing on an "as-is" scenario that represents current operations without the integration of new technologies. Work was meticulously quantified in uniform "packages of phase products" to ensure consistent measurement across all stages. For the purpose of financial valuation, the "market" value of a hypothetical ship was conservatively set at an estimated $1.2 billion, a figure derived from the total projected price to the U.S. Navy for the Arleigh Burke (DDG51) destroyer [32]. Additional critical values were sourced from established KVA models of naval operations and corroborated with expert modeler estimates. Applying the Knowledge Value Added (KVA) methodology, this aggregated value was systematically allocated across the 12 distinct shipbuilding phases. This allocation was rigorously calibrated in units of learning time, referencing a common point learner, thereby ensuring a standardized basis for comparative analysis.

The subsequent "to-be" scenario within the system dynamics model focused on simulating the strategic integration of three specific advanced technologies into the shipbuilding process. The initial phase involved establishing a baseline performance by simulating operations under as-is conditions. Following this, the potential impacts of incorporating these three technologies into various shipbuilding phases were quantitatively assessed. This quantification primarily manifested as fractional reductions in both rework fractions and operation duration. The observed reductions in rework fractions directly reflect the anticipated improvements in quality (e.g., enhanced early error detection) resulting from technology adoption, consequently diminishing the need for subsequent corrective operations. Conversely, the reductions in operation duration signify the increased processing speed and efficiency achievable through the application of these technologies. It is imperative to note that these fractional reductions are predominantly based on conservative modeler estimates, informed by actual reductions documented in relevant scholarly and industry literature. This deliberate conservative approach was adopted to minimize the likelihood of overestimating the technologies' potential benefits.

The projections of substantial operational improvements are robustly supported by empirical evidence drawn from multiple industries with close ties to shipbuilding, as well as by documented cost savings experienced directly by naval operations. Illustrative examples of such reductions from practical applications include:

- ❖ Operation duration decreasing from 100 to 42 hours.
- ❖ 39% reduction in operation duration achieved by the Navy through the use of 3D Laser Scanning.
- ❖ Operation duration being compressed from 4 months to just 4 days.
- ❖ Time savings of 43% realized through the application of Additive Manufacturing (AM).

These examples collectively underscore the tangible and significant advantages anticipated from the strategic integration of these advanced technologies within contemporary shipbuilding processes, validating the model's underlying assumptions.

See Housel *et al.* (2015) for additional support of rework and duration reductions. The reduction fractions were combined with the as-is calibration values to generate values for the to-be simulation. These values were used to simulate shipbuilding operations using three technologies. Table 1 shows the average completion rates of the 12 phases for the as-is (without technologies) and to-be (with technologies) scenarios.

Table 1. Simulation results: average completion rates of shipbuilding phases for as-is and to-be scenarios.

AVERAGE COMPLETION RATE (*work packages/ day*)			
NO	SHIPBUILDING PHASE	AS-IS SCENERIO	TO-BE SCENERIO
1	Conceptual design	0.593	0.8958
2	Detailed design	3.115	4.454
3	Pre-construction planning	1.407	1.741
4	Block fabrication	3.084	9.502
5	Block assembly and outfitting	2.865	11.61
6	Keel laying and block erection	3.439	13.53
7	Pre-delivery outfitting	3.439	13.53
8	System testing	2.047	3.508
9	Sea trials	6.34	6.896
10	Post-delivery outfitting	3.273	13.27
11	Post-delivery test	1.827	1.963
12	Post-shake down maintenance	1.827	1.963

Source: Defense ARJ, July 2020, Vol. 27.

The outputs derived from the system dynamics simulations of both the "as-is" (current operations) and "to-be" (technologically integrated operations) shipbuilding scenarios served as the foundational input for the Knowledge Value Added (KVA) model. This integrated analytical approach enabled the estimation of Return on Investment (ROI) for each individual process within each respective scenario. The calculated KVA-derived ROI values, alongside the projected changes in ROI directly attributable to the adoption of the new technologies, are comprehensively presented in Table 2. This table, therefore, provides a quantitative representation of the financial benefits anticipated from the strategic implementation of the advanced technologies in shipbuilding operations.

Table 2. Estimated changes in naval shipbuilding return on investment due to use of three innovative technologies.

NO	SHIPBUILDING PHASE	AS-IS ROI (%)	TO-BE ROI (%)	CHANGE IN ROI (%)	AUTOMATION TOOLS
1	Conceptual design	−2	9.4	9.6	AM, PLM
2	Detailed design	561	1826	1265	AM, PLM
3	Pre-construction planning	218	244	25	PLM

Continued

4	Block fabrication	−67	−51	36	3DLS, AM, PLM
5	Block assembly and outfitting	−17	−31	133	3DLS, AM, PLM
6	Keel laying and block erection	−63	1	64	3DLS, AM, PLM
7	Pre-delivery outfitting	505	1270	764	3DLS, AM, PLM
8	System testing	280	582	301	3DLS, PLM
9	Sea trials	1018	961	−57	PLM
10	Post-delivery outfitting	476	1243	767	3DLS, AM, PLM
11	Post-delivery test	239	282	42	PLM
12	Post-shake down maintenance	221	201	−20	PLM
	TOTAL	**135**	**465**	**329**	

Source: Defense ARJ, July 2020, Vol. 27.

Table 2 shows that the Detailed design (No. 2), Post-delivery outfitting (No. 10), and Pre-delivery outfitting (No. 7) phases of shipbuilding benefit the most from the use of the technologies; and that the Sea trials (No. 9) and Post-shake-down maintenance (No. 12) benefit least. Of more significance, the aggregate ROI for all processes combined increased by 329%.

The definition of ROI, the estimated benefits ($1.2 billion), and the as-is and to-be ROI values in Table 2 were used to estimate costs with and without technology adoption. The difference between these costs is $296.91 million and reflects the estimated potential savings for one hypothetical ship. This represents a potential savings of 24.74% ($296.91 million/$1,200 million) of the total cost to the Navy. This savings fraction is conservative when compared with the results reported by industry adopters of these technologies (e.g., up to 70% for AM) [33].

4. Conclusion and Recommendation

Owing to the president's vision on building America's economy and rescuing it form it $32 trillion debt, it is crucial to invest in new infrastructures that the past administrations did not focus on and that is the shipbuilding industry. Despite having very low funding, the input of the private shipbuilding to the America's economy is so great to be neglected and it is clearly evident that if the industry has a government funding, it can be one of the easiest ways to achieve the America we have all dreamed about and fulfill the president's mandates. Also, the scale and cost of the Navy's shipbuilding plan require the exploitation of advanced technologies. The four discussed technologies 3DLS, AM, PLM and the intelligent ship can beneficially impact many phases of shipbuilding industries in multiple operations to reduce the costs and improve the value of shipbuilding core processes. As seen from the common practices of the Asian Tigers how government funding and policies, technological integration, and the merger of smaller shipbuilding industries into a giant industry helped shaped and reposition them to their respective global rankings, overcoming triumphantly the challenging times.

To quantify the impact of 3D Laser Scanning (3DLS), Additive Manufacturing (AM), and Product Lifecycle Management (PLM) technologies on shipbuilding processes, a phase-level simulation model of shipbuilding operations was constructed. This model generated two distinct scenarios: one reflecting operation without these technologies, and another incorporating their use. The simulation outputs were subsequently fed into a Knowledge Value Added (KVA) model of naval shipbuilding. This KVA model then determined the Return on Investment (ROI) for shipbuilding under both technological conditions. Ultimately, these ROI estimates enabled the calculation of shipbuilding costs with and without the technologies, thereby projecting the potential savings achievable through their implementation.

Simulation results suggest that the U.S. shipbuilding industry can save at least 24% and almost $300 million on the acquisition of a representative ship if the potential improvements available through 3DLS, AM, PLM and i-ship are fully exploited. These estimates support the assertion that these technologies can improve naval shipbuilding and indicate that the Navy should acquire and use these advanced technologies in shipbuilding as soon as possible to minimize cost and for improve capabilities.

With the President Donald Trump creation of the Maritime Action Plan (MAP) shows the relevance of this article to tackle the retrogressive movement of the US shipbuilding industry and a restoration of the US hegemony in the global economy.

Recommendation

Advanced technology adoption issues should be considered when implementing the previous recommendation. Those issues include whether the four technologies are to be implemented concurrently, which requires a larger budget and bears more uncertainties, or introduced more sequentially and selectively, which slows value creation. Adoption plans should also consider the capabilities of specific shipbuilders and how to best scale up the use of the new technologies.

The current work has assumed steady state technology use after adoption of the tools. How to acquire and implement these tools is a particularly important issue that future research can investigate, as is the viability and cost of transporting the range and quantities of the "feedstocks" that 3DLS machines need to make different parts.

The work has contributed to understanding the value of innovative technologies, to the US shipbuilding industry, specifically, the Naval shipbuilding and potentially other naval operations. Continued modeling and analysis of technology investments can facilitate their adoption and use by the Navy and therefore increase value while reducing costs.

The recent emergence of Internet of Things (IoT) technologies in different industries has led shipyards around the world to be interested in applying the same technology to the naval industry, and this application has been called the Internet of Ships (IoS). IoS is the application domain of IoT in the naval industry, and refers to the network of smart and interconnected objects, which can be any physical device or infrastructure associated with a shipyard, a vessel, a port or sea transport itself, with the aim of significantly driving the naval industry towards an improvement in terms of safety, efficiency and environmental sustainability.

Finally, the open challenges presented and future opportunities for naval research, safety, ship data collection, management and analysis provide a road map towards the full application of IoS in the naval sector.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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