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# USE OF SHIPBUILDING 4.0 TECHNOLOGIES FOR ENHANCING THE LIFE CYCLE MANAGEMENT OF NAVAL SHIPS

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## ABSTRACT

*Shipbuilding 4.0, having developed from Industry 4.0, has been making a substantial imprint in shipbuilding organization and operation, across many countries worldwide. In the present era, where the expansion of the world navies is being restrained by budget availability for new ship acquisition, the use of Shipbuilding 4.0 in the Life Cycle Management of naval ships will enhance some opportunities for optimizing the Life Cycle Cost of their fleet on the efficiency and effectiveness fronts. Adapting Shipbuilding 4.0 involves implementation of advanced technologies such as Robotics and Automation, Digital Twins, Internet of Things (IoT), Big Data Analytics, Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), and Additive Manufacturing which could exert substantial influence on all the Life Cycle Management of naval ships. The article examines how the various Shipbuilding 4.0 technologies may be integrated within the Life Cycle Management of naval ships to* *improve Logistics Support quality and optimize Life Cycle Costs. The integration of the Shipbuilding 4.0 also introduces numerous challenges to address, particularly with regard to the security of operational and engineering data, much of which constitutes classified military information.*

**Keywords:** Shipbuilding 4.0, Maintenance, Life Cycle Management (LCM), Naval Ships, Logistics Support, Life Cycle Cost (LCC), Maintenance Cost, Ship Availability.

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## 1. Introduction

Naval vessels tend to be exceedingly invaluable assets, usually with complicated designs and long operational lifetimes. Therefore, life cycle management becomes imperative in ensuring efficient and effective management throughout its life that extends from 25 to even 30 years and beyond. Life Cycle Management of a naval ship involves the management of design and engineering activities, construction, operations, upkeep, upgrades, and disposal: that is, it looks after everything it does from the beginning to the end.

Emerging technologies related to Shipbuilding 4.0 are now opening up a multitude of uses for maximizing and improving the Life Cycle Management of naval ships by further enhancing the basic and existing methods and practices in design, construction, operation, maintenance, upgrades, and ultimately, disposal of naval ships. Shipbuilding 4.0 is primarily the application of digital and advanced technologies to enhance and optimize all the activities of the life cycle of naval ships-from concept to decommissioning in general and ship building in particular, and it is based on the principles and concepts of Industry 4.0.

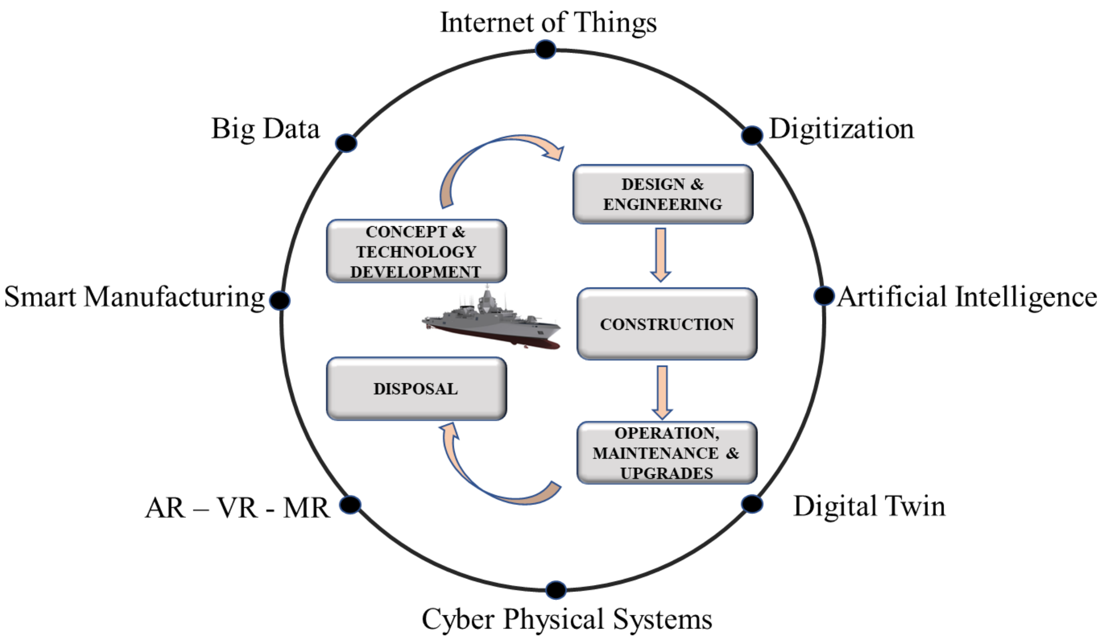


**Figure:** Integration of Shipbuilding 4.0 into Life Cycle Management of Naval Ships

Use of these modern technologies and digital solutions as part of Shipbuilding 4.0 will make a significant improvement in all aspects of Life Cycle Management for naval ships by increasing their operational availability and optimizing the Logistics Support requirements and associated maintenance costs. While there are multiple benefits from the integration of principles, concepts, methodology, and practice of Shipbuilding 4.0 technologies into the Life Cycle Management of the naval ship, challenges accompany the integration. The most critical challenges arise are the ones concerning to the operational and engineering data security issues since it is part of the classified military information.

## 2. Overview of Shipbuilding 4.0

Shipbuilding 4.0, evolving from Industry 4.0, aims to bring a radical transformation of the shipbuilding and ship repair industry through advanced technologies. Industry 4.0 gives a broad and general meaning to technologies disrupting connectivity, data, computational power, analytics, and intelligence, human-machine interaction and advanced engineering technologies (McKinsey & Company, 2022).

Shipbuilding 4.0 innovations offer the prospect of improving the safety, availability, reliability, and maintainability of ships, systems, and equipment, thereby optimizing logistic support requirements and reducing Life Cycle Costs. All the activities involving design, construction, operation, and maintenance are extremely complex and labour-intensive. Shipbuilding 4.0 can greatly increase the efficiency and effectiveness of these activities by embedding the solutions it offers. Some of these advanced technologies presented to improve productivity and competency in the shipbuilding or ship repair industry include Robotics and Automation, Cyber Physical Systems, Digital Twins, Internet of Things (IoT), Big Data Analytics, Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), and Additive Manufacturing.

The modern shipyards leading the shipbuilding and ship repair industries utilize automated technology and robotic systems to carry out labour-intensive activities, such as welding, blasting, painting, inspections, heavy lifting, etc. The use of robotics and automation not only enhances precision and quality, but improves the safety and efficiency in the activities related to the construction, operation, and maintenance of naval ships, systems, and equipment on board.

Digital Twin represents a virtual equivalent of a physical ship or its component that can be used for simulation, monitoring, and optimization over the life cycle of a ship. Although the Digital Twin Technology was primarily introduced for the in the realm of Product Life Cycle Management in general, by integrating the three key elements – the physical product, its virtual equivalent and the connecting data-link the Shipbuilding 4.0 is widely extending its use in to the naval shipbuilding and ship repair activities in shipyards across the world. The Digital Twin draws on real-time data from a network of integrated or distributed sensors and digital devices helping to create information necessary for predictive maintenance, fault detection and identification, reliability and availability monitoring, and life cycle forecasting, all to ensure efficient operations of naval vessels.

IoT in Industry 4.0 and Shipbuilding 4.0 terminology is defined as the interconnected network of devices, sensors, and systems that collect, exchange, and analyse data in real-time. IoT devices are connected to the shipboard machineries gathers real-time data from the equipment and the information generated out of such data is analysed to detect the anomalies, initiate predictive maintenance, and resource optimization (Kaplan, 2024). In naval vessels, IoT technologies when implemented, would predominantly allow for the effective management of various ships systems such as the propulsion systems, electrical systems, HVAC systems, and the Navigation and Communication Systems.

Big Data and Data Analytics are a part of Shipbuilding 4.0 that deals with the collection and analysis of large amounts of data from ships especially during the operation of the ship and the equipment onboard, to improve the decision-making. Analytics of operation and maintenance data will aid in assessing the condition of the ship systems and equipment to identify the maintenance requirements, improving the fuel efficiency, reduction of the emissions and environmental impact, improving in the visibility of the supply chain, and safety of personnel onboard (Rao & CS, 2024).

Artificial Intelligence, which mimic the human intelligence, is another aspect of Industry 4.0 and thereby Shipbuilding 4.0, which has mainly come in machines that are programmed to think, learn, and perform tasks characteristic of human intelligence. Machine learning is a sub-field of artificial intelligence that focuses on the development of algorithms that allow computers to learn from data and usually bring about performance enhancement without any specific programming inputs through manual interventions. Application of Artificial Intelligence and Machine Learning will enhance shipbuilding and ship repair optimising the hull design, makes the systems and equipment efficient, predictive maintenance, and maintenance optimization (Kumar et al., 2024).

Additive manufacturing, such as 3D Printing, is the process through which the parts are built by position of materials such as composite or plastic, in an additive fashion layer-by-layer using unlike the subtractive technology such as CNC machines which are based on the integration of CAD/CAM technology (Abdulhameed et al., 2019). 3D Printing combines rapid prototyping with the manufacture of complex components and reduced lead time, allowing customization of ship parts more efficiently.

Shipbuilding 4.0 also brings in the use of Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) into the shipbuilding and maintenance domains by integrating it primarily with the training, operations and maintenance processes associated with the ship, systems and equipment onboard. Augmented Reality adds or augments digital information such as images, sounds, or data onto the real-world scenarios. What the user sees is being enhanced by adding digital elements to the real environment permitting interaction with the real world while seeing the extra digital elements. Virtual Reality facilitates a fully immersive experience where the user is completely immersed in a virtual environment and interacts only with that virtual world and not the physical world. Mixed Reality combines the features of Augmented Reality and Virtual Reality to provide the user experience.

## 3. Life Cycle Management of Naval Ships

Life Cycle Management (LCM) of ships involves the coordinate management of all the activities, especially the logistic support activities, throughout a ship's existence, including the design, engineering, construction, operation, maintenance, upgrades and disposal or decommissioning. To ensure LCM works well and produces the desired results, navies must efficiently and effectively manage the ships, systems, and equipment for their entire service life. This means keeping them running and performing at their best, making them safer, and optimizing their overall cost. Navies worldwide use various methods, approaches and techniques to implement LCM for ships, systems and equipment onboard. Some popular maintenance strategies to develop ways to manage naval assets in accordance with the LCM concept include Condition-Based Maintenance (CBM), Reliability-Centered Maintenance (RCM) and Predictive Maintenance.

Navies around the world now use several approaches for the management of the assets. These include In-Service Support (ISS), Through Life Support (TLS), Through Life Asset Management (TLAM), and Through Life Capability Management or Through Life Asset Management (TLCM). Managing a naval ship's life cycle plays a key role in getting the best performance, reliability, availability, and maintainability, while keeping costs down over its service life. A good life cycle management plan does more than just keep ships ready for action. It also helps cut down on costs for maintenance. This happens by choosing the right ways to use resources, plan budgets, and avoid waste. Having these plans for naval ships helps to manage them efficiently and to reduce the risks associated with the system. This is very critical for defence systems, given the dangers of operations and the need to keep people safe. Naval assets are often complex and work in tough conditions for long stretches. Therefore, efficient Life Cycle Management is necessary to ensure that the ship, systems and equipment onboard can be used when needed and to deliver the designed output.

## 4. Integrating Shipbuilding 4.0 into Life Cycle Management of Naval Ships

The integration of Shipbuilding 4.0 concepts and technologies into the Life Cycle Management of the naval ships is bound to bring in revolutionary transformation in shaping the future of naval shipbuilding and its sustainment. Leveraging the advanced digital technology and state-of-the art automation solutions offered by Shipbuilding 4.0, shipyards and navies could improve their efficiency in the design, construction, operation, maintenance and upkeep of the naval ships. Some of the major Shipbuilding 4.0 concepts which are being integrated to the Life Cycle Management of naval ships by the shipyards and navies across the world include the Robotics and Automation, Digital Twin Technology, IoT Devices, Artificial Intelligence and Machine Learning, Big Data Analytics and 3D Printing Technologies.

Use of Robotics and automation during the construction phase of the life cycle help in precise construction of the ships as well as for the calibration and operation of the equipment and systems onboard the ships, which enhances their safety and efficiency while decreasing the human errors and associated production and downtimes. The use of robotics for activities such as painting and welding during the construction as well as the operational phase ensures precision and quality of the work undertaken for maintenance and upgrades, in addition to the optimization of the resource requirements for such jobs, which are otherwise labour intensive. Robotics and automation also help in the maintenance processes such as hull cleaning of the ships and for diagnostics of equipment during the operation, maintenance and upgrade phases.

The digital twin technology is used to establish a virtual representation of the ship, system or equipment onboard in digital format. Digital twins of naval ships are established using the design and engineering data, normally during the initial phase of the ship's life cycle and progressively updated throughout the service life of the asset to simulate and replicate its functions and operations. During the design phase of the asset life cycle, the digital twin technology is also used by the shipbuilders to test the designs under simulated conditions and optimize various aspects of the ship, such as stealth, speed, energy efficiency, safety, and performance, prior to their physical construction. This approach helps in decreasing the duration of the design phase and also the overall cost of acquisition. During the operational phase, the digital twin not only helps in monitoring the operational availability of the ship, system or equipment onboard, but also facilitate the advanced identification of the deterioration of any performance parameters in order to initiate the specific maintenance activities in a proactive manner.

In shipbuilding 4.0, IoT is used to connect machinery, tools, ships, materials and workers, to enable seamless communication and data sharing across the entire shipbuilding, operation and maintenance life cycle of the ship, systems or equipment onboard. Unlike the conventional monitoring of the equipment and systems through periodical inspections of the localized sensors and gauges, the IoT enables continuous monitoring of the key operating parameters of the systems and equipment onboard the ships during the operational phase, thereby helping in timely detection of anomalies to prevent the failures and downtimes. Existence of a reliable and rugged IoT infrastructure is pivotal for the establishment of a digital twin of the ship, system or equipment onboard, for remote monitoring and simulations. IoT also enables real-time tracking of materials in the shipyard as well as onboard the ships, for efficient management of spares, tools and test equipment during the construction and operational phase of the naval ships. Remote diagnostics of the systems and equipment are also undertaken with the help of advanced software applications through IoT during the operational phase of the naval ships, especially while the ships are away from the base ports for long term deployments. IoT, combined with the robotics and Artificial Intelligence is the key for automation of the shipbuilding and maintenance processes as well as for enabling the autonomous ship operations.

Big Data and Data Analytics is a key element in the implementation of Shipbuilding 4.0. Large amount data is collected from ships predominantly during operation and maintenance activities and thereafter analysed for improved decision-making. Data pertaining to the ship, systems and equipment are also collected during the construction phase, which normally serves as the base line for the future operations and maintenance. Big Data aids in predictive analytics which in turn helps to optimise the maintenance schedules, assess the health of ship, systems and equipment onboard, and improve the reliability, availability and maintainability of the assets while improving their safety. Big Data in Shipbuilding 4.0 is constituted by the large volumes of structured and unstructured data generated from various sources during the shipbuilding, operation and maintenance process. While the operational and performance data are normally obtained through the sensors integrated with the ship's machinery and equipment through IoT, the logistics, engineering and design data are obtained through the respective application software used by the shipyards and the navies. Big Data Analytics involves the processing and analysing of the large volumes of data thus obtained, in order to extract meaningful insights, identify patterns, and support the decision-making, especially in terms of operational and logistics planning.

In order to facilitate the optimization of the logistics support, it is necessary to capture and record good quality and quantity of data during the various phases of ship’s life cycle. Therefore, special emphasis shall be accorded for data management in the Life Cycle Management programs of the naval ships, right from the design and engineering phases until the decommissioning. The data obtained from the sensors through IoT are analysed in real-time or in offline modes using appropriate software tools to extract the necessary inputs for logistical, operational and maintenance decision making. By monitory the construction processes and the associated data, opportunities could be identified for production process optimization. Big Data and Data Analytics could be used for improving the ship designs by analysing the data from simulations, real-time performance data, and historical design projects, in order to ensure safety, enhance the efficiency and reduce the Life Cycle Costs. Optimizing the maintenance plans, improving the process of procurement and management of spares, planning and strategizing on the ship’s life extension programs, etc. during the ship’s operational phase, are some of the other key areas which will directly benefit from the Big Data and Data Analytics as a part of the Shipbuilding 4.0. During the operational phase, the condition of critical ship equipment can be monitored in real-time by using sensors and IoT networks, and the data thus obtained could be used for predictive analytics to identify any imminent failures and to initiate proactive maintenance for improving their availability. Use of Big Data and Data Analytics during the life cycle of ships could also help in the implementation of a robust and efficient inventory management process.

The Big Data captured during the various phases of the life cycle of the ship is analysed using Artificial Intelligence and Machine Learning to generate meaningful information for logistical, operational and maintenance decision making. During the design and engineering phase of the ship’s life cycle, Artificial Intelligence could be used to analyse the large volumes of data to identify the best design parameters. Use of robotic systems integrated with Artificial Intelligence could be used for the automation during the construction and operational phases for the production, installation, commissioning and maintenance of the ship, systems and equipment onboard, could improve the overall safety, quality and resource utilization. Artificial Intelligence and Machine Learning technologies could be used for further enhancement of the Smart Ships concept wherein the ships perform the navigational and operational decision making in real-time. Artificial Intelligence and Machine Learning

In Life Cycle Maintenance, additive manufacturing aids in the maintenance and repair of naval ships by providing on-demand spare parts (Zhao et al., 2023). Use of the additive manufacturing into the Life Cycle Management of naval ships happens mainly during the operational phase, especially during the later stages of the ship’s service life. Additive manufacturing technologies are mainly aimed at the production of complex or custom parts that either are too difficult or too expensive to manufacture by traditional or obsolete methods. In addition, rapid prototyping via 3D printing during design and engineering has significantly lowered the cost of such prototyping and hence shortened the time that components of a ship are tested and refined. Through 3D printing, spare parts can be manufactured just in time, especially the structural components for the ship’s outfitting and the mechanical components required for auxiliary systems, thereby reducing costs related to inventorying parts, while allowing greater availability of such parts for maintenance or repair.

Augmented Reality (AR) allows shipbuilders to visualize 3D models of the ships, systems, and equipment in diverse scenarios. Augmented Reality applications help engineers in comprehending how parts fit together in the real environment, identifying potential design issues during the design and engineering stages of the ship's life cycle, before actual construction and assembly begins. During construction, the overlay of markings, instructions, and parameters can be implemented through augmented reality during the installation and commissioning of systems and equipment. In the operational phase, Augmented Reality can assist in overlaying instructions, drawings, and technical information on systems and equipment during maintenance or repair. This process enhances efficiency and also ensures safety by strictly adhering to the relevant processes and procedures. Augmented reality could also be used for the training of the operators and maintainers by facilitating the overlay of virtual information on the systems and equipment, enabling the hands-on learning without the risk of making costly mistakes.

Use of Virtual Reality (VR) in Shipbuilding 4.0 makes it possible for the designers to provide an immersive experience of the ship, systems and equipment onboard in a virtual scenario during the design and engineering phase of the ship’s life cycle, even before the ship is built physically. This not only helps to identify the changes and modifications required, but also helps in improving the overall ergonomics and maintainability. Similar to the Augmented Reality, Virtual Reality could also be used for the training of the operators and maintainers in simulated scenarios prior to providing the respective training in real world scenarios. Virtual Reality could also be used by the designers for collaborative development of the design and for simulating the various operating environments during the design and engineering phases to study the effect of various factors affecting the ships stability, reliability and performance.

## 5. Conclusion

Shipbuilding 4.0, which has evolved from Industry 4.0, has been making significant impact on the organisation and operations of the shipbuilding sector across the world. At a time when the world navies are restrained by budget constraints for their fleet expansion and the upgrade of their aging ships, the use of Shipbuilding 4.0 in the Life Cycle Management of naval ships will enhance some opportunities for optimizing the Life Cycle Cost of their fleet while at the same time provide opportunity for improving their efficiency and effectiveness. Implementation and exploitation of the Shipbuilding 4.0 technologies has the potential to revolutionize not only the shipyard processes associated with the design, engineering and construction phase of the ship's life cycle, but also to bring in major changes in the management of ship and the equipment onboard during their operational and maintenance phases. Several shipyards across the world have already implemented or are in the process of implementation of Shipbuilding 4.0 technologies and exploiting their vast capabilities, thereby yielding results which are definitely going to bring down the Life Cycle Cost of the naval ships in the long run.

Although the integration of Shipbuilding 4.0 with the Life Cycle Management of the naval ships provides several benefits such as improvement of efficiency, effectiveness and the safety associated the ships, systems and equipment onboard, there are also several challenges to implementing these technologies. The implementation of the high-end technologies such as Robotics, IoT, Artificial Intelligence, Machine Learning, Augmented Reality, Virtual Reality etc. demands huge initial capital expenditure for the software, hardware and the associated training.

As the Shipbuilding 4.0 technologies are state-of-the-art, its integration with the legacy equipment would be complex and costly. Training and development of the shipyard and naval personnel to work on these advanced technologies is likely to be a challenging affair. As the Shipbuilding 4.0 is dependent upon the IoT networks and the digital platforms, they would require extremely stringent cyber security systems to protect them from any kind of intrusions or cyber-attacks, which would not only endanger the operations of the ship, systems and equipment, but also jeopardise the military missions and compromise national security. However, in spite of these challenges in implementing state-of-the art and complex Shipbuilding 4.0 technologies, the potential benefits are substantial, making its adaption, implementation and integration into Life Cycle Management of naval ships, critical and essential for the modern navies.

## References

[1] Abdulhameed, O., Al-Ahmari, A., Ameen, W., & Mian, S. H. (2019). Additive manufacturing: Challenges, trends, and applications. Advances in Mechanical Engineering, 11(2), 168781401882288. https://doi.org/10.1177/1687814018822880.

[2] Kumar, S., University of California, Irvine, Shukla, D., & Experian. (2024). Harnessing Machine learning for Innovations in Shipbuilding: Techniques and applications. International Journal of Research and Analytical Reviews, 11(3), 126–127.

[3] Kunkera, Z., Opetuk, T., Hadži´C, N., & Tošanovi´C, N. (2022). Using digital twin in a shipbuilding project. Appl. Sci., 12, 12721. https://doi.org/10.3390/app122412721.

[4] McKinsey & Company. (2022, August 17). What Is Industry 4.0 and the Fourth Industrial Revolution? McKinsey & Company. https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-are-industry-4-0-the-fourth-industrial-revolution-and-4ir.

[5] Rao, N. D., & CS, N. A. (2024). Challenges and opportunities of big data analytics for maritime and shipping industry. International Journal of Engineering Technology and Management Sciences, 8(1), 83–90. https://doi.org/10.46647/ijetms.2024.v08i01.011.

[6] Zhao, N., Parthasarathy, M., Patil, S., Coates, D., Myers, K., Zhu, H., & Li, W. (2023). Direct additive manufacturing of metal parts for automotive applications. Journal of Manufacturing Systems, 68, 368–375. https://doi.org/10.1016/j.jmsy.2023.04.008.

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