JKSCI

한국컴퓨터정보학회논문지
Journal of The Korea Society of Computer and Information
Vol. 29 No. 11, pp. 353-369, November 2024
https://doi.org/10.9708/jksci.2024.29.11.353

Establishment of backcasting-based strategic approach and resilience-based AI governance for the transformation of artificial intelligence in Korean shipbuilding industry

Changhee Lee*, Sangseop Lim*

*Professor, Div. of Navigation Convergence Studies, Korea Maritime and Ocean University, Busan, Korea

[Abstract]

This paper presents strategies for enhancing productivity and strengthening global competitiveness as the domestic shipbuilding industry transitions into the era of Artificial Intelligence Transformation (AX), moving beyond digital transformation. Historically a labor-intensive industry, shipbuilding has evolved into smart shipyards powered by automation and digitalization, with increasing emphasis on green regulations and the importance of green fuels. The urgent adoption of alternative fuels, such as ammonia and liquid hydrogen, is critical in this context. However, the industry faces new challenges amid intensifying global competition and rapid technological changes. This study analyzes both domestic and international cases of AI transformation and the adoption of eco-friendly fuels in shipbuilding companies, proposing ways to manage risks through the establishment of AI governance to ensure sustainable growth. In particular, by utilizing the backcasting method, the study sets short-term, mid-term, and long-term goals while deriving phased strategies to provide significant insights and implications for policy formulation and corporate strategies aimed at the AI transformation of the domestic shipbuilding industry while complying with environmental regulations.

▸ **Key words**: AI transformation, Green Regulation, Green Fuels, Ammonia, AI governance, Backcasting

[요　약]

본 연구는 국내 조선산업이 디지털 전환을 넘어 인공지능(AI) 기반의 전환(AX) 시대를 맞이함에 따라, AI를 활용한 생산성 향상과 글로벌 경쟁력 강화 방안을 제시한다. 과거 노동 집약적인 산업이었던 조선업은 자동화와 디지털화를 거쳐 현재 AI 기반의 스마트 조선소로 진화하고 있으며, 친환경 규제와 친환경 연료의 중요성이 증가하고 있다. 특히, 암모니아, 액화수소 등와 같은 대체 연료의 도입이 시급한 상황이다. 그러나 글로벌 경쟁 심화와 기술 변화 속에서 새로운 도전에 직면하고 있다. 본 연구는 국내외 조선기업의 AI 전환 및 친환경 연료 채택 사례를 분석하고, AI 거버넌스를 구축하여 리스크를 관리하고 지속 가능한 성장을 위한 방안을 제시하였다. 특히, 백캐스팅 기법을 활용하여 친환경 규제를 준수하면서 단기, 중기, 장기 목표를 설정하고, 단계별 전략을 도출하여 국내 조선산업의 AI 전환을 위한 정책 수립 및 기업 전략 수립에 중요한 시사점과 의의가 있다.

▸ **주제어**: AI 전환, 친환경규제, 친환경연료, 암모니아, AI 거버넌스, 백캐스팅

• First Author: Changhee Lee, Corresponding Author: Sangseop Lim
*Changhee Lee (chlee@kmou.ac.kr), Div. of Navigation Convergence Studies, Korea Maritime and Ocean University
*Sangseop Lim (limsangseop@kmou.ac.kr), Div. of Navigation Convergence Studies, Korea Maritime and Ocean University
• Received: 2024. 10. 21, Revised: 2024. 11. 18, Accepted: 2024. 11. 18.

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http://www.ksci.re.kr pISSN:1598-849X | eISSN:2383-9945
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I. Introduction

Since 2023, the domestic shipbuilding industry has entered the era of AI transformation (AX: Artificial Intelligence Transformation), moving beyond mere digitalization to address green regulations and the adoption of alternative fuels such as ammonia and liquid hydrogen. While automation has been integrated into processes like steel cutting and assembly, complex tasks such as pre-painting and outfitting still rely heavily on manual labor. AI transformation aims to create an AI-based digital platform throughout the entire shipbuilding process—from design to processing, outfitting, painting, and sea trials—while ensuring compliance with environmental standards.

Korean shipbuilding companies are pursuing strategic innovation through this transformation policy to enhance productivity, efficiency, sustainability, and competitiveness in the face of green regulations. The essence of AX is to build upon existing digital transformation (DX) efforts and propel collaborative growth among large, medium, and small shipbuilders centered around AI and eco-friendly practices.

Historically, the domestic shipbuilding industry led the market, achieving the highest order volumes until the early 2000s. However, following the 2008 global financial crisis and challenges from competitive Chinese shipyards, the Korean industry faced significant setbacks. The bankruptcy of major companies like Hanjin Shipping is exacerbated by rising raw material prices, leading to substantial restructuring.

With the global shipbuilding market rebounding since late 2020, the Korean shipbuilding industry has regained some momentum, recording approximately $23 billion in orders in 2021. Yet, by 2023, China regained the edge in competitiveness, primarily due to its government-led shipbuilding and marine integration strategy.

This study focuses on whether innovative growth strategies through AI and digital transformation are essential for the domestic shipbuilding industry to remain competitive against China and achieve future growth. The Korean shipbuilding industry must now adopt comprehensive strategies to address the limitations of its traditional labor-intensive model, seizing opportunities to improve productivity and safety, particularly in addressing long-standing labor shortages through AI-based automation.

Moreover, AX is anticipated to be crucial in tackling labor shortages, with AI and robotics transforming traditionally labor-intensive processes. However, successful AX implementation requires not only the adoption of automation but also robust AI governance to manage associated risks effectively. Therefore, this study aims to assess the strategic necessity of preserving Korea's shipbuilding competitiveness, emphasizing the importance of AX in the context of eco-friendly regulations and ammonia fuel adoption.

To support this, the research examines the impact of AI on shipbuilding through historical analysis and presents a framework for a resilient AI ecosystem. It further analyzes various domestic and international AI transformation cases to identify challenges and opportunities while applying a backcasting strategic approach to establish effective AX goals for Korean shipbuilders. Ultimately, this study proposes a governance plan to enhance the competitive edge of the Korean shipbuilding industry in the global market while achieving sustainable growth.

II. Previous Studies and Methodology

2.1 Analysis of the historical growth of artificial intelligence and the great transformation in the shipbuilding industry

DX and AX are distinct concepts. DX refers to the process of automating and digitalizing existing industries using information and communication technologies (ICT) such as 5G, cloud computing,

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and IoT to improve productivity. In contrast, AX is a more advanced concept than DX, utilizing artificial intelligence (AI) technology to integrate AI across a company's business processes, products, and services with the goal of optimized operations. AX goes beyond simple automation, pursuing an innovative process where AI learns independently and builds optimal processes, transforming the core of the industry to be AI-driven. [1] As this innovative process has recently permeated various industries, the demand for AX is rapidly spreading, with AI technology actively being introduced in fields such as computers and electronics, financial services, healthcare, shipbuilding, factories, shipping and ports, and aviation logistics. [2]

From a modern perspective, Korea's shipbuilding industry, with a long history of cycles of growth and decline, has become one of the nation's key infrastructure industries, closely linked to the domestic economy. Korea's shipbuilding industry originated during the Japanese colonial period, starting as a labor-intensive industry centered around manual work in port cities like Busan, Incheon, and Ulsan. It later went through processes of automation and digitalization in shipbuilding processes in response to the development of unit technologies such as sequencing, systems, and networking. [3] Recently, with the introduction of AI technology, the industry is experiencing an unprecedented AX, which can be analyzed in terms of the following growth stages.

The first stage is the transformation of the labor-centered shipbuilding industry. The early shipbuilding industry was a labor-intensive sector that required a large workforce. Korea's shipbuilding industry began in 1929 with the establishment of the Bangojin Iron Works and entered full-scale industrialization in 1937 with the founding of Chosun Heavy Industries (now Hanjin Heavy Industries). At that time, most of the shipbuilding processes, including design, construction, and maintenance, were dependent on dedicated designers, and the skills and experience of skilled workers were key to the development of the industry. [4]

The second stage is the shift to automation-centered shipbuilding. In the 1970s, with the government's policy to promote heavy and chemical industries, the modernization of the shipbuilding industry began in earnest. Since the 1980s, the introduction of robotics and automation technology led to the replacement of simple and repetitive tasks, such as welding, assembly, and crane operation, with automated machinery at shipyards. Large shipbuilding companies, including Hyundai Heavy Industries, Samsung Heavy Industries, and Daewoo Shipbuilding & Marine Engineering, significantly improved productivity through large-scale facilities and automation technologies. As a result, Korea's shipbuilding industry quickly surpassed Japan and solidified its position as the world's second-largest shipbuilding powerhouse. [5]

The third stage is the innovation of shipbuilding centered on digitalization. In the 2000s, DX became a new growth engine for the shipbuilding industry. The digitalization of ship design and production processes was realized through the introduction of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies, and the limited use of Digital Twin technology implemented virtual shipyards to maximize productivity and efficiency. [6]

The fourth stage is the shift to AI-centered shipbuilding. Recently, the shipbuilding industry has been intensifying efforts to transition from digitalization to an AI-based intelligent automation system. AI supports process optimization across the entire process of design, production, and maintenance through autonomous learning and predictive analysis. AI-based predictive maintenance systems, through real-time monitoring of ships and shipyard equipment, determine the optimal maintenance timing, reducing costs and improving operational rates. [7] This AI-based transformation does not rely on labor-intensive methods or simple automation but introduces a

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new operating method in which AI independently learns and optimizes processes. This transition serves as the foundation for the development of a sound and safe shipbuilding industry by reducing operating costs and efficiently allocating manpower

2.2 AI Governance in the Resilience-Based Shipbuilding Industry

Resilience Theory explains the ability of a system to absorb, adapt, or quickly recover when faced with external stress, shocks, changes, or crises. [8] As Resilience Theory forms an important theoretical framework for crisis management and enhancing resilience in various fields such as psychology, organizational studies, disaster management, and engineering, this study aims to utilize Resilience Theory to interpret and support the adaptability of a specific organization's system amid the uncertainties and complexities that shipbuilding companies face in the fast pace of innovation and change. For Korean shipbuilding companies to successfully undergo the AX transformation, it is essential to establish AI governance based on resilience, which includes the following four detailed elements:

First, absorption refers to the ability of a shipbuilding company to manage the organization in a way that minimizes the impact of internal and external shocks, ensuring that the system can continue functioning normally. Second, adaptation is the capability of the system to flexibly respond to and adjust to a changing and innovative environment while maintaining its essential structure, allowing the system to adapt to changes and innovations. Third, recovery is the system's ability to quickly restore itself to a normal state after an internal or external shock, with the balance of sustainability and stability being a critical factor. Lastly, transformation goes beyond simply returning to a previous state, indicating the ability to structurally reorganize the system and evolve in an upright state, turning crises into opportunities. [9]

Resilience Theory provides a critical theoretical framework for establishing AI governance for Korean shipbuilding companies in the rapidly changing technological environment and global competition. Particularly, the unregulated introduction of AI technology poses the risk of collapsing existing shipbuilding industry systems and significantly increasing the complexity and uncertainty of shipbuilding processes. Therefore, managing the technical and operational risks associated with these threats is crucial. In this context, resilience-based AI governance focuses on enhancing the resilience of shipbuilding companies to flexibly respond to internal and external threats, while maximizing competitiveness and efficiency through AI technology. It also serves as the foundation for creating a management system that swiftly responds to the various tangible and intangible risks that existing organizational systems may face.

Resilience-based AI governance continuously monitors the entire life cycle of AI technologies applied to the shipbuilding industry, detecting and eliminating unforeseen risks in advance to ensure stable operation of AI systems. [10] In this process, the concept of traditional governance theory plays a crucial role, and the governance theory that this study will focus on is New Governance Theory, which emerged after the 1980s in response to pluralistic social changes. This theory emphasizes a collaborative management approach where various stakeholders—government, the market, and civil society—form networks and participate in solving public issues. This study applies this concept because, for shipbuilding companies to successfully adopt a governance system that reflects the complexity of AI technology, collaborative relationships with entities such as the government, labor organizations, local communities, ship finance institutions, classification societies, shipping companies, ship equipment manufacturers, and educational and research institutions are essential. [11]

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Thus, considering the following three factors, resilience-based AI governance acts as an essential strategic tool to ensure that shipbuilding companies achieve global competitiveness and sustainability, successfully leading the AI transformation. First, resilience-based AI governance must establish a management system to ensure that the introduction and operation of AI systems at shipyards are not merely technological innovations but are conducted in a stable and sustainable manner. Second, resilience-based AI governance is suitable for systematically managing the technical risks and threats that may arise throughout the entire life cycle of AI technology. Third, resilience-based AI governance ensures that the digital transformation driven by AI technology is pursued in a sustainable manner, allowing the shipbuilding industry to maintain competitiveness in the global market and promote long-term growth.

2.3 Theoretical Methodology

This study aimed to present a strategic analysis and AI governance framework to successfully lead the AX transformation in the Korean shipbuilding industry. By combining backcasting theory with AX case studies, the study identified strategic tasks and designed an improvement-oriented analysis framework to apply these insights. The strategic approach of this study focuses on identifying opportunities and challenges associated with AI technology adoption, designing AI governance to recover global competitiveness and foster sustainable growth, and systematically analyzing the complex interactions and dynamic changes that arise during the AX transition process in shipbuilding companies, ultimately suggesting optimized improvement directions. [12]

First, this study conducted a comparative literature review based on various cases of AI transformation in domestic and international shipbuilding companies. Through literature research, it reviewed the significant changes and innovations brought about by AI adoption and digitalization in the shipbuilding industry and analyzed the key factors required for the successful application of AI technologies. The study provided critical insights into the components and management systems necessary for designing AI governance, systematically analyzing cases of AI-based management and production innovations in shipyards that succeeded through AX.

Second, this study conducted a comparative analysis of AI transformation cases from domestic and international shipbuilding companies, evaluating the outcomes and challenges encountered during the AI adoption process. It identified the innovations and achievements arising from AI-based technology adoption in these companies and studied the major risks that could occur during AI adoption and operation, along with strategies for mitigating these risks. Through examples of changes in shipbuilding companies that applied AI technologies such as Digital Twin and predictive maintenance systems, the study analyzed how AI transformation is being implemented in the shipbuilding industry and derived key implications.

Third, the study designed a strategic roadmap with step-by-step goals for a successful AI transformation using the backcasting method. Backcasting set specific goals for the short, medium, and long term, focusing on the transformation and development of shipbuilding companies with AI at the core, and proposed a phased approach to achieving these goals. Through this methodology, the study identified the role of AI governance and the strategies for addressing risks and driving innovation. Particularly, the backcasting method offers a clear strategic roadmap to achieve future AI transformation goals, providing an effective means to identify and prepare for various risks that may arise during the AI transformation process.

Fourth, to ensure the successful advancement of AI transformation, this study aims to design an AI governance framework. AI governance comprises four main stages: prevention, detection,

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containment, and response, ensuring that AI systems operate stably. This framework seeks to identify potential risks in advance during the AI adoption process in shipbuilding companies, manage these risks effectively, and ensure that AI technologies are applied stably to shipbuilding processes. Through this process, the study focuses on continuously monitoring the entire shipbuilding lifecycle using AI technologies, with the main objective of preventing data management and cybersecurity issues.

Fifth, in terms of research contributions, this study proposed specific strategies and an AI governance framework to overcome the challenges faced by the shipbuilding industry through AX, while enhancing global competitiveness and sustainability.

III. Various Challenges and Opportunities Based on Case Studies for Artificial Intelligence Conversion of Domestic and Foreign Shipbuilding Companies

This study aims to systematically analyze the ways in which AI technology maximizes productivity and efficiency in the shipbuilding industry, as well as to identify the various niche opportunities and challenges that arise in the process by examining AX cases implemented by major domestic and international shipbuilding companies. To this end, the study explores the successful adoption and operation of AI technologies in global shipbuilding companies such as HD Hyundai Heavy Industries, Samsung Heavy Industries, Hanwha Ocean (formerly Daewoo Shipbuilding & Marine Engineering), Italy's Fincantieri, and China's Wuhu Shipyard. Through these cases, the complex interactions occurring during the realization of AI-based smart shipyards were analyzed as follows.

3.1 Domestic and Foreign Case Studies

3.1.1 HD Hyundai heavy industries

HD Hyundai Heavy Industries is building an AI-based shipyard system through the FOS (Future of Shipyard) project. The FOS project consists of three phases, with the goal of improving productivity by 30% and reducing shipbuilding time by 30% by utilizing AI and digital twin technologies. The first phase involves visualizing shipyard site information in 3D, enabling shipbuilding process managers to monitor the work status in real time. The second phase integrates information such as personnel, materials, and equipment through AI to automate the periodic management of shipbuilding processes, establishing a master plan for optimal resource allocation and efficient shipbuilding. The third phase aims for full automation of the entire shipyard by 2030, where minimal management personnel will be able to oversee shipbuilding through AI and robotics. In this way, HD Hyundai Heavy Industries' strategy to drive automation and digitalization throughout the shipyard plays a crucial role in ensuring competitiveness and sustainability in the global shipbuilding market.[13]

3.1.2 Samsung heavy industries

Samsung Heavy Industries is promoting AI-based digital transformation through the Smart SHI (Smart Samsung Heavy Industries) project, optimizing design, procurement, and production based on ICT (Information and Communication Technology). The first phase of Smart SHI, which began in 2020, focused on intelligent shipbuilding production systems, advanced planning, and innovation in work methods. This led to achievements in productivity improvement and cost reduction through shipbuilding automation. The second phase, starting in 2024, expands the scope of the smart ecosystem across the entire shipyard, enhancing data integration related to shipbuilding processes with internal and external partners and domestic and international shipbuilding equipment suppliers. Through this, Samsung Heavy Industries

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is maximizing overall shipyard efficiency. A notable example is the 'Integrated Monitoring System (Smart Samsung YARD),' a management platform that uses IoT, AI, and other technologies to convert vast amounts of structured and unstructured data into big data, analyze it, and visualize it for real-time use. Samsung Heavy Industries has also developed an AI-based chatbot called S-Bot (Smart Samsung BOT). This chatbot allows shipbuilding managers to ask questions in natural language, and the AI analyzes the query to provide optimal answers by drawing from design know-how, regulations, contract information, and historical management data stored in the system, thus enhancing efficiency, stability, and economic performance.[14]

3.1.3 Hanwha ocean

Hanwha Ocean is implementing a smart yard by incorporating big data and AI technologies. Notably, it is optimizing processes through AI-based digital twin technology and improving decision-making accuracy across all stages from design to production and operation by introducing an AI-based data analysis system. Hanwha Ocean is promoting automation in the block assembly and welding stages by integrating advanced digital technologies such as AI and the Internet of Things (IoT) into shipbuilding. For example, the company uses the Long-G robot for welding internal parts, one of the most challenging processes, improving both the shipbuilding process and safety. In the long term, Hanwha Ocean aims to solve issues in all welding areas by expanding the application of its proprietary robot design and control technology. Additionally, Hanwha Ocean has developed 'Real Blast,' a training program using VR for pre-treatment tasks such as removing rust from steel plates before painting. This program, linked with ship blasting training, has reduced the training period for new employees from one year to half. At the trial stage, Hanwha Ocean is also developing ships and systems that enable remote control of operations from land, with plans to implement a fully autonomous navigation support system by 2030 in the shipyard [15].

3.1.4 Fincantieri shipbuilding

As of 2024, Fincantieri, a global leader in the shipbuilding industry with 18 major shipyards worldwide, is accelerating the development of technology innovation projects for the digitalization of ships, ports, and marine infrastructure through a strategic partnership with Accenture, a global professional services company with extensive expertise in digital innovation across industries such as cruise, defense, and port services. Fincantieri's shipyards maximize efficiency in shipbuilding processes through AI and digital twin technology. The shipyard, through an AI-based platform provided by Accenture, analyzes vast amounts of data in real-time to derive optimal designs and anticipates potential issues in the production process, enabling proactive responses. Fincantieri has also introduced a system that simulates and monitors all stages of shipbuilding using AI-based digital twin technology, in collaboration with Traxens in France. This system enables real-time monitoring and data analysis of shipbuilding processes, contributing to improved accuracy and efficiency. Fincantieri's case of AI-based digital twin technology is recognized as a successful example of digital transformation in the shipbuilding industry, driving innovation in process management and design while enhancing data-driven decision-making and cybersecurity [16].

3.1.5 Wuhu shipbuilding

Since its establishment in 1900, China's Wuhu Shipyard has strengthened its competitiveness in the global shipbuilding industry by adopting robotics and unmanned automation. Through the Wuhu Shipyard (Weihai) Green Marine Technology Industrial Base project, Wuhu is pioneering the first unmanned shipbuilding plant in the industry. The shipyard has revolutionized shipbuilding processes

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by introducing intelligent robot systems and automated production lines. By applying robot technology to various workstations, including AI-based intelligent cutting, blanking, assembly, and welding, Wuhu has automated previously manual tasks. For example, Wuhu employs eight welding robots and T-beam welding robots for multi-block welding and uses AI-based Automated Guided Vehicles (AGVs) to transport and assemble ship blocks and components autonomously. Wuhu also combines advanced dynamic visual technology with AI-enhanced machine learning algorithms linked to big data, achieving high-level human-machine collaboration in shipbuilding processes. By optimizing resource allocation within the factory through an intelligent central control system, Wuhu has successfully minimized errors and waste in shipbuilding. As a result, Wuhu's unmanned shipbuilding plant is recognized as the world's first fully unmanned shipbuilding facility and marks a significant milestone in China's advancement toward AI-driven shipbuilding technology [17].

3.1.6 Implications

To strengthen global competitiveness, domestic shipyards must fully adopt AI and digital twin technology to accelerate the transition from traditional shipbuilding methods and maximize productivity and efficiency through AX. As shown in <Table 1> and based on advanced cases like Fincantieri, AI-based digital twin systems that integrate real-time data and predictive maintenance systems contribute to enhancing operational efficiency by predicting potential issues throughout a ship's lifecycle. Similarly, domestic shipbuilders need to expand AI-based automation technologies to improve precision and safety in production processes, as demonstrated by China's Wuhu Shipyard, which has realized unmanned production processes by integrating IoT and robotics. In other words, domestic shipbuilders must enhance productivity and competitiveness across the entire shipbuilding lifecycle through AX based on AI and IoT technologies, creating momentum to lead the global trend in AX within the shipbuilding industry."

Table 1. Comparison of AX strategies and key features of domestic and foreign shipbuilding companies

	AI and Digital Twin Strategy	Main Feature	Focused Sector
HD Corp	FOS (Future of Shipyard) Project: Aiming for a 30% increase in productivity and a 30% reduction in construction time through the establishment of a three-phase AI and digital twin system.	3D visualization, automation of resource allocation, and the goal of constructing ships with minimal management personnel by 2030.	Integration of AI in automation, resource optimization, and construction management.
Samsung	Integration of AI in automation, resource optimization, and construction management.	Integration and prediction of supply chain data with a data-based platform (SYARD) and AI chatbot (SBOT).	Real-time data monitoring, integration of shipbuilding supply chains, and AI-based information sharing support for internal and external staff.
Hanwha	Implementation of smart yards based on big data and AI: Introducing process optimization through digital twin technology and AI-based data analysis systems.	AI-based decision-making, VR-based training systems, and use in autonomous ship research.	Application in manufacturing: AI and robotics application, virtual reality training, development, and commercialization of eco-friendly autonomous ships.
Fincantieri	Managing the entire life cycle of ships through AI and digital twins, utilizing real-time data integration and advanced simulation systems.	Supporting real-time data-based decision-making, predictive maintenance, energy optimization, and collaboration with specialized third-party solution providers such as Traxens.	Optimization of the entire shipbuilding process cycle through AI-based digital twins: Real-time monitoring and process simulation.
Wuhu Corp.	Implementation of a fully automated shipyard and unmanned shipbuilding processes through robot-based welding and AI-based dynamic visual technology.	Operation of an AI-based welding robot, automatic transport and assembly using AGVs, and the world's first unmanned shipyard.	Operation of an AI-based welding robot, automatic transport and assembly using AGVs, and the world's first unmanned shipyard.

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3.2 Challenges and Opportunities to AX of Korean Shipbuilding Companies

3.2.1 Purpose

From a backcasting perspective, the main objectives of AX for Korean shipbuilding companies can be divided into three key areas. Firstly, from the perspective of efficiency improvement, Korean shipbuilding companies should utilize AI technology to automate repetitive and routine tasks, predict future scenarios based on data, and reduce time and costs, thereby setting a direction for improving the shipbuilding process. Secondly, from the perspective of creating new value by using substitutes instead of labor, Korean shipbuilding companies should use AI to innovate existing business models and develop products and services such as ships and offshore plants with embedded new technologies, expanding opportunities for sustainable profit generation. Thirdly, from the perspective of enhancing shipbuilding competitiveness, Korean shipbuilding companies should use AI technology to secure a leading position as global technological leaders in the new shipbuilding market, respond to the rapidly changing new shipbuilding market environment, and set a direction for capturing new opportunities.

3.2.2 Challenges in terms of technology, environment, employment, and organization

Firstly, overcoming challenges related to technical limitations. One of the biggest challenges in the digital transformation process of Korean shipbuilding companies is the threat of cybersecurity and the limitations of technology standardization. Despite the rapid development of technologies such as AI, IoT, and big data, there is a lack of standardization and platformization to integrate these technologies for interoperability and building a bespoke digital twin service. Additionally, many Korean shipbuilding companies are still in the early stages of building digital infrastructure, resulting in vulnerabilities in network security and data management. Specifically, companies like Hanwha Ocean, HD Hyundai Heavy Industries, and SK Ecoplant are engaged in the U.S. Navy's Maintenance, Repair, and Overhaul (MRO) business. Consequently, the introduction of AI systems in this sector poses potential risks of data hacking and system malfunctions, threatening the stability of production processes and new business operations [18]. Secondly, overcoming challenges related to pressures in global competition. As previously examined, Chinese and European shipbuilding companies are gradually progressing with AI transitions, exerting both tangible and intangible pressure on Korean shipbuilding companies. Chinese shipyards, which compete with Korean shipbuilding companies, are actively adopting unmanned factories and robotics technologies, thereby reducing production costs and maximizing shipbuilding process efficiency. In contrast, Korean shipbuilding companies are still limited to partial adoption of some technologies, posing a risk of falling behind in global competition. If the digitalization speed gap is not bridged, competitiveness in price, quality, and delivery in the global shipbuilding market could decline [19]. Thirdly, overcoming challenges related to employment stability for shipbuilding workers. Digitalization and the introduction of AI are expected to have significant impacts on the employment market in the shipbuilding industry. As AI technology replaces direct and indirect labor involved in repetitive tasks within shipbuilding processes, job reductions and increased demands for redeployment and retraining of both direct and subcontracted workers are expected. Therefore, the potential for increased anxiety among workers due to employment stability issues is high, which could develop into a new core agenda for labor-management conflict. Ultimately, changes brought about by AX not only affect productivity at shipbuilding sites but can also negatively impact the overall atmosphere of production, design, and sales departments [20]. Lastly, overcoming challenges related to innovation in AI-based

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organizational culture. For the successful implementation of AX in domestic shipbuilding companies, it is essential to change the traditional manufacturing-based organizational culture. If the top management, middle management, and frontline workers within shipbuilding companies have resistance to AX, the overall speed and efficiency of AX could decrease. In particular, the lack of artificial intelligence literacy and low adaptability to new technologies among employees in shipbuilding companies could lead to difficulties in embracing innovation and change [21].

3.2.3 Opportunities in terms of technology development, productivity, cooperative networks, and global competitiveness

There is the aspect of capturing opportunities related to the development of new technologies such as eco-friendly autonomous ships. AX can play a crucial role in promoting the development of technologies related to eco-friendly autonomous ships within shipyards. Utilizing AI-based eco-friendly ship fuel management systems and digital twins can maximize ship energy efficiency and contribute to developing eco-friendly technologies that reduce ship carbon emissions. Furthermore, the introduction of these new technologies can contribute to long-term cost savings and ESG improvements for shipbuilding companies. There is the aspect of capturing opportunities related to productivity improvement across the shipbuilding process. AI, big data, and digital twin technologies present opportunities to maximize the productivity and efficiency of shipbuilding companies. Particularly, maintenance systems can extend the lifespan of equipment and maximize the efficiency of the shipbuilding process through process automation. Additionally, AI-based design optimization and real-time monitoring systems can minimize errors in the ship design and production process, reducing overall process costs [22]. There is the aspect of capturing opportunities related to enhanced government support and cooperation. Utilizing government AI-related DX support policies and cooperative platforms such as the K-Shipbuilding Next-Generation Initiative can promote AI transformation in the shipbuilding industry through specialized workforce training and technical support. As of 2024, the Ministry of Trade, Industry, and Energy plans to train 1,000 specialists annually in future fields such as AI, big data, eco-friendly ships, autonomous ships, and smart yards, enhancing expertise across the shipbuilding industry and enabling successful AI transformation through talent supply [23]. There is the aspect of capturing opportunities related to strengthening global competitiveness. If domestic shipbuilders successfully establish AI-based smart shipyards, they can further enhance their competitiveness in the global shipbuilding market. If AI-based digital transformation projects pursued by HD Hyundai, Samsung Heavy Industries, and Hanwha Ocean are successfully completed, they can secure a unique position in the global shipbuilding industry through productivity improvement and process efficiency. Particularly, AI-based smart shipyards can instill trust in global shipowners and significantly increase competitiveness in the high-value-added ship market.

3.2.4 Implications

The introduction of AI is becoming an essential element for enhancing competitiveness in the shipbuilding industry, providing significant implications in various aspects. The adoption of AI technology plays a crucial role in improving productivity in the shipbuilding industry. Particularly, AI, big data, and digital twin technologies enable automation and optimization throughout the processes of ship design, manufacturing, and maintenance, minimizing human errors and maximizing process efficiency through predictive maintenance. These technologies can practically contribute to productivity improvement and process duration reduction in the shipbuilding process, helping domestic shipbuilding companies achieve specific goals such as over 30% productivity improvement.

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AI can act as an important means to promote the creation of innovative new technologies, such as the development of eco-friendly and autonomous ships. AI-based fuel management systems and digital twin technologies can maximize ship energy efficiency and reduce carbon emissions. This is essential not only for responding to international environmental regulations but also for providing opportunities to significantly enhance competitiveness in the eco-friendly ship market. Furthermore, the introduction of AI technologies will play an important role in helping shipbuilding companies achieve ESG (Environmental, Social, Governance) goals. The adoption of AI technologies entails challenges related to security issues and the lack of technology standardization. Despite the rapid development of AI and IoT technologies, enhancing data management and system security remains a crucial task. Particularly, cybersecurity threats can undermine the stability of production processes and business activities, which is a problem that must be addressed to successfully lead AI adoption in the global shipbuilding industry. AI adoption can significantly impact the employment structure in the shipbuilding industry, necessitating worker redeployment and retraining. As repetitive tasks are automated, changes in the existing workforce structure are likely, requiring systematic measures to ensure employment stability for successful management. Organizational cultural innovation is essential to minimize internal conflicts during the AI adoption process and enhance adaptability to new technologies.

Therefore, preparing an AI transformation roadmap based on the backcasting methodology is necessary. Backcasting involves setting ultimate goals and specifically formulating step-by-step strategies to achieve them, which is an effective approach for AI transformation. Additionally, establishing an AI governance system to comprehensively manage cybersecurity, ethical issues, and employment stability is essential. Such a governance system will play an important role in ensuring that the AI transformation in the shipbuilding industry is conducted in a stable and sustainable manner.

IV. Establishment of a backcasting-based roadmap and AI governance for AX of Korean shipbuilding companies

4.1 Prerequisites for Successful AX of Shipbuilding Companies

The AI-driven transformation in the shipbuilding industry demands not only technological advancement but also enterprise-wide changes and organizational restructuring. Strategic leadership and the establishment of AI governance are essential for successful implementation. Therefore, to gain an edge in global competition and promote sustainable growth, Korean shipbuilding companies need the following strategic approaches:

The introduction of AX leadership and strengthening organizational learning are necessary. AX leadership involves agility and experience-based leadership, facilitating vertical and horizontal participation of organizational members in AX and acceptance of AI technologies. Therefore, leaders of shipbuilding companies must present a clear vision and guide members to recognize the importance of AI and digital technologies. This approach minimizes resistance to change and innovation, enhancing the overall AI acceptance and learning culture within the organization [24]. The efforts to reduce risks associated with AI adoption through the spread of AI literacy and fostering a collaborative culture are crucial. Leaders should provide systematic in-house training programs related to AI to ensure that members of shipbuilding companies understand AI technologies and can effectively apply them to their work. This approach reduces inefficiencies that may occur during the early

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stages of AI adoption and chooses a gradual diffusion strategy to enhance adaptability to new technologies [25].

The risk management through the establishment of AI governance is necessary. The introduction of new technologies, including AI, can bring not only technical but also legal and social issues. AI governance provides a structure to systematically manage these risks, allowing shipbuilding companies to prevent and respond to various problems that may arise during the adoption process. Particularly, through AI governance, shipbuilding companies can utilize enhanced cybersecurity and data management as key risk avoidance strategies in the AI transition [26]. Formulating an AX strategy for sustainable development is essential for maintaining and strengthening competitiveness in the global market [27]. Specifically, AX strategies support shipbuilding companies in flexibly responding to rapidly changing technological environments and market demands. Given the shipbuilding industry's characteristics, requiring large-scale capital and long production cycles until the production of completed ships, failure to quickly adapt to rapid eco-friendly and digital transitions in the global new shipbuilding market can pose significant risks. Therefore, through AI transformation, Korean shipbuilding companies must rapidly adopt and commercialize new technologies, such as eco-friendly ships and autonomous ships, to create new market opportunities. Establishing a collaborative network based on the Multiple Helix Model, centered around shipbuilding companies, and involving various stakeholders is necessary [28]. Especially, through support from government and local municipalities, educational and research institutions, the shipbuilding industry can enhance specialized workforce training and technical support, promoting AI transformation. Additionally, collaboration with labor unions and other organizations should ensure that AI technologies meet environmental and social responsibilities, creating sustainable development strategies.

4.2 Backcasting-Based Strategy and Success Roadmap for AX

To successfully lead the AX of shipbuilding companies, a systematic and phased approach is essential. This AX strategy should be divided into short-term, mid-term, and long-term strategic plans, with each phase identifying actionable tasks to be gradually implemented [29]. Therefore, this study uses the backcasting method as the core methodology to derive research results, aiming to establish a strategic roadmap for AI transformation by setting future goals and outlining steps to achieve them. The ultimate goal of AX for shipbuilding companies is to comprehensively integrate AI and digital twin technologies to enhance global competitiveness and sustainability. To realize this, AX should be approached in stages as illustrated in <Table 2>, ensuring that the success of each phase informs subsequent projects.

Firstly, the short-term (1-2 years) goal is to build digital infrastructure and initiate AI-based experimental projects. This phase involves preparing educational programs to enhance AI literacy for internal and external organizational members, and introducing AI technologies into design and operational departments to achieve tangible results. For instance, digital twin technology can be experimentally applied to unit organizations between test ships and shipyards, as well as between ships needing post-delivery service (A/S) and shipyards. Based on these results, the feasibility of AX-based maritime data exchange should be evaluated, laying the foundation for broader adoption. This phase aims to build consensus on AI transformation within the organization and accelerate early-stage technology adoption by establishing AI-based equipment and maritime data analysis systems.

Secondly, the mid-term (3-5 years) goal is to expand AI and digital twin technologies across the organization and achieve productivity improvement and process efficiency in key departments of shipbuilding companies through digital transformation. At this stage, the CEO of the

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shipbuilding company must exercise strong AI leadership by introducing AI-based production management systems to enhance the digitalization and optimization of shipbuilding processes enterprise-wide. Additionally, middle managers and above should extend AI-based digital twin technology to shipyards, overseas production bases, and overseas test ships, maximizing the efficiency of design, production, and testing processes. AI-based maintenance systems should be introduced to reduce excessive costs in shipbuilding processes and improve productivity. The mid-term phase should focus on embedding these AI-enabled digital devices and operational systems within the company's infrastructure and maximizing the results of AI transformation.

Thirdly, the long-term (5-10 years) goal is to complete the enterprise-wide AX and establish a leading position in the global shipbuilding industry through the application of AI in shipbuilding processes. To achieve this, it is crucial to integrate AI throughout the shipbuilding process, maximizing automation and efficiency, and ultimately leading the development of eco-friendly autonomous ships. AI technology should optimize all stages of shipbuilding, from design and production to maintenance, ultimately developing eco-friendly autonomous ships. Additionally, an AI governance system must be established to detect and respond to risks associated with AI technology adoption and operation. This ensures the stable and reliable operation of AI technology, enhancing the competitiveness and sustainability of shipbuilding companies in the global market. Long-term, AI governance will be foundational for shipbuilding companies to take a leading role in the global shipbuilding ecosystem through effective international cooperation and AI technology exchange with various stakeholders.

Table 2. Step-by-step strategic goals, strategic tasks, and implementation strategies of shipbuilding companies necessary for AX

Phase	Goals	Strategic Tasks	Implementations
Short-term (1-2 years)	Establish AI-based digital infrastructure and initiate AI-based experimental projects.	Prepare educational programs for AI literacy. Apply digital twin technology experimentally to test ships and shipyards, as well as during the post-delivery A/S process. Establish AI-based equipment and maritime data analysis systems.	Form consensus on AI transformation within and outside the organization. Accelerate the introduction of initial stage AI technologies.
Mid-term (3-5 years)	Enterprise-wide dissemination of AI and digital twin technologies and productivity improvement.	Introduce AI-based production management systems. Implement predictive maintenance systems. Expand the application of digital twin technology to remote sites.	Strengthen AI-based process automation and optimization. Extend successful AI adoption results organization-wide.
Long-term (5-10 years)	Complete enterprise-wide AI transformation and establish a leading global position.	Integrate AI technology throughout the shipbuilding process. Lead the development of eco-friendly autonomous ships. Establish AI governance systems and strengthen international cooperation.	Establish risk management systems through AI governance. Play a leading role in the global shipbuilding industry.
Key Factors	Flexibility, leadership, acceptance of AI transformation, a learning system for success, and an AI governance framework within the organization.		

As these short-, mid-, and long-term strategic tasks are pursued based on their goals, the most critical factor is the organizational culture regarding latent momentum and willpower. The shift to an AI-centered organizational culture must emphasize transforming not only technological innovation but also the overall culture and mindset of the organization. The introduction of AI technology involves not just adopting new

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technology but creating an environment where organizational members can work effectively within a new AI environment and form a changing culture. Therefore, a strategy should be pursued to experimentally introduce AI transformation in each organizational unit, achieve small-scale successes, and gradually expand them organization-wide. Consequently, Korean shipbuilding companies need an AI governance system that applies a phased incremental approach with feedforward to minimize the risk of failure and evaluate and apply successful cases in subsequent stages [30].

4.3 AI Governance Model of Resilience-Based Shipbuilding Companies for AX

The adoption of artificial intelligence (AI) in shipbuilding companies is not only about technological innovation but also a crucial element of a sustainable growth strategy that enhances resilience to external shocks and changes. The successful application and safe operation of AI technology hinge on the establishment of resilience-based AI governance. This governance acts as a critical management framework to achieve multifaceted goals such as productivity improvement, enhanced safety, and compliance with International Maritime Organization (IMO) environmental regulations through AI technology. AI governance provides a managerial framework tailored to the characteristics of the shipbuilding process, ensuring transparency and accountability while establishing a system that can quickly adapt and recover from unforeseen risks, minimizing risks associated with technology adoption and maximizing operational efficiency [31].

4.3.1 Resilience-Based AI Governance System

The essential first step for the adoption of AI technology is compliance with domestic and international regulations and laws related to the shipbuilding and maritime industry. Specifically, the design and operation of AI systems must reflect IMO conventions and regulations, class society rules, and individual national laws. Continuous legal analysis and regulatory updates are necessary for this purpose. To manage this, an AI governance dedicated organization should be established to handle policy responses, regulatory compliance, and external cooperation, enhancing the system's adaptability and resilience through regular monitoring and improvement activities. A resilience management system should be established to quickly identify and respond to potential risks of AI systems, such as seafarers' human rights issues, cyber terrorism, data errors, and safety problems, thereby preparing for the unique risk factors of the shipbuilding industry [32].

4.3.2 Feedforward-based omnidirectional AI adoption strategy and issue management

An important role in the AI governance system, reflecting the characteristics of the shipbuilding industry, is the resilience-based AI pyramid strategy. The feedforward-based omnidirectional AI adoption strategy is a system that comprehensively evaluates the risks and opportunities that may arise throughout the lifecycle of AI technology. Introducing a repetitive audit system at each stage of design, production, operation, and maintenance to evaluate risks and secure adaptability and resilience to predicted risks can optimize the shipbuilding process and achieve results such as predictive maintenance [33]. Therefore, even after AI technology is applied throughout the shipbuilding process, shipbuilding companies must thoroughly verify each stage in a feedforward manner and continually manage to ensure stable and reliable operation of AI systems even in the event of cyber terrorism or emergencies. It is essential to establish early response protocols for swift responses to issues such as ethics, environment, human rights, safety, and fairness that may arise during AI system operation [34]. For instance, if system errors or worker safety issues occur during the shipbuilding process, the causes must be quickly analyzed, and improvement measures must be prepared. Through this, it is

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necessary to algorithmically prevent recurring problems in the shipbuilding process based on machine learning problem-solving.

4.3.3 An Example Structural Model with Key Principles of Resilience-Based AI Governance Design

To ensure the successful adoption of AI technology in the shipbuilding industry, it is essential to guarantee transparency and accountability while also ensuring adaptability and resilience to external shocks. The AI-based decision-making process must be systematically explained, as illustrated in Figure 1, so that all stakeholders clearly understand the principles of AI model operation and data processing methods, with responsibilities clearly defined at each stage [35]. Furthermore, creating an atmosphere where not only the CEO but also managers and workers in the design and operational departments understand and can apply AI technology in practice is necessary. This involves fostering a resilience-based AI literacy (AI Literacy) environment within the organization. Through this, efficient operation and safety of AI technology can be ensured, and AI can support optimized operations across all processes, including design, production, and maintenance.

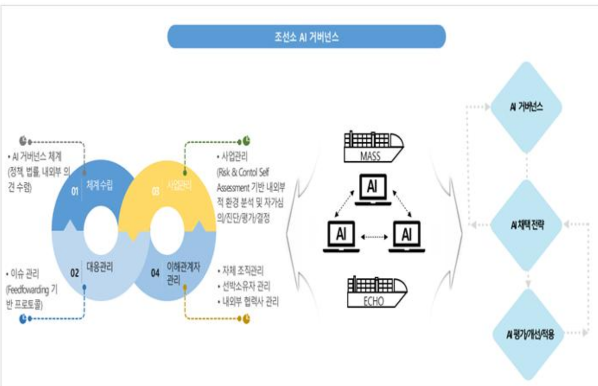

Fig. 1. Exemplary Resilience-Based Shipyard AI Governance Design Model

V. Conclusion

This study offers a strategic approach to support the AI transformation of Korean shipbuilding companies and provides insights for establishing AI governance. It emphasizes the need for significant AI-centered innovations to achieve sustainable growth in the competitive global shipbuilding market. Utilizing the backcasting method, the study sets mid- and long-term goals for AI transformation and presents a strategic roadmap for achieving these objectives.

The research underscores that AI is crucial for enhancing productivity, reducing costs, and developing eco-friendly technologies in shipbuilding. It highlights the significance of digital twins, predictive maintenance, and automated processes based on AI. By analyzing AI transformation cases from major shipbuilding companies like HD Hyundai Heavy Industries and Samsung Heavy Industries, the study confirms their success in improving productivity and reducing shipbuilding times using AI and digital twins.

Additionally, the importance of resilience-based AI governance is discussed. While AI adoption brings technological innovations, it also introduces risks such as cybersecurity threats and data management issues. Thus, establishing AI governance rooted in resilience theory is essential for firms to respond effectively to external challenges. The study outlines actionable short-term (1-2 years), mid-term (3-5 years), and long-term (5-10 years) goals. Short-term objectives focus on building AI infrastructure and conducting pilot projects, while mid-term goals aim at widespread AI and digital twin technology adoption. Long-term goals center on completing AI transformations and securing global market competitiveness.

In conclusion, the research asserts that AI transformation demands a paradigm shift in the industry and proposes a systematic management strategy for this transition. It highlights that establishing AI governance can enhance operational

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efficiency and global competitiveness. Notably, this study's findings contribute academically by providing a phased strategic roadmap and AI governance framework for effectively leading the AI transformation in the shipbuilding sector.

This study's limitations include the lack of quantitative assessment of AI adoption and its effects in individual shipyards, as well as a focus on larger firms, which may limit the generalizability of the findings. Future research aims to address these gaps by collecting quantitative data and developing indicators to evaluate AI adoption maturity across a broader range of shipbuilding companies.

ACKNOWLEDGEMENT

This research was supported by Korea Institute of Marine Science and Technology Promotion (KIMST) funded by the Ministry of Oceans and Fisheries, grant number RS-2023-00236321.

This research was supported by the Ministry of SMEs and Startups(MSS), Korea Institute for Advancement of Technology(KIAT) through the Innovation Development(R&D) for Global Regulation-Free Special Zone

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Authors

Changhee Lee earned his M.A and Ph.D degrees in Maritime Law from Korea Maritime and Ocean University, Korea in 2012 and 2014. Dr. Lee is currently a professor in the Division of Navigation Convergence Studies at Korea Maritime and Ocean University, Busan, Korea. He is interested in maritime law, legal distpute in shipbuilding contract, and maritime policy.

Sangseop Lim received the B.S. degree in ship engineering and M.A. and Ph.D. degrees in shipping management from Korea Maritime and Ocean University, Korea, in 2007, 2014 and 2018, respectively.

Since 2020, Dr. Lim is currently assistant professor in the Division of Navigation Convergence Studies at Korea Maritime and Ocean University, Busan, Korea. He is interested in shipping finance, shipping market forecasting and risk management.

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