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Digitalization Transformation and its Challenges in Shipping Operation: The Case of Seafarer's Cognitive Human Factor

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ABSTRACT

Industry 4.0, as the most disruptive industrial revolution, is reshaping the industries by coupling the cyber to the physical systems. The current digitalization has its root in digitization introduced by Industry 3.0, where it made a foundation for gradual industrial migration to Industry 4.0. Respectively, Shipping 3.0 introduced automation and computerized systems onboard ships and paved the way for entering to Shipping 4.0. In turn, the ultimate goal of Shipping 4.0 is the full autonomy through implementation of autonomous shipping. The introduction of the autonomous shipping not only modifies the maritime workplaces but also changes the jobs' definitions and the role of seafarers as the human element in the system. However, the journey to Shipping 4.0 will takes shipping industry to different steps before ships become fully autonomous. International Maritime Organization (IMO) defined these steps in four degrees from traditional to smart shipping. This implies that, at the same time, seafarers' role and the required skills and competencies to gradually evolve with the ships transition to the next degree. The review of literature about Industry 4.0 shows that so far, the focus of researchers and the industry is mainly on the innovation in technology and its implementation on ships. However, the role of the human and the cognitive human factor in the process is yet to be investigated. This paper aims to explore the effects of adaptation of digitalization in the shipping industry with a focus on the human element and cognitive human factor. The paper illustrates how the innovation and technological development of Industry 4.0 is changing the shipping industry and evolving human operators' roles, responsibilities, and training needs.

Keywords: Industry 4.0, Seafarer 4.0, Shipping 4.0, Cognitive human factor, Autonomous shipping, Maritime education and training, MASS

INTRODUCTION

The world, so far, has been through four industrial revolutions each led to major changes in the work and the role of human in the workplace. As the time lapse between industrial revolutions is getting shorter, the human as workforce have been increasingly experiencing more challenges to conform to their new roles. Likewise, the maritime industry went

Table 1. Industrial revolution and the resultant shipping, operator, and seafarer revolutions. (Shahbakhsh, Emad, & Cahoon, 2021) (Romero et al., 2016).

Industrial Revolution	Timeline	Shipping Revolution	Timeline	Operator Revolution	Seafarer Revolution
Industry 1.0	Around 1784	Shipping 1.0	Around 1800	Operator 1.0	Seafarer 1.0
Industry 2.0	Around 1870	Shipping 2.0	Around 1910	Operator 2.0	Seafarer 2.0
Industry 3.0	Around 1969	Shipping 3.0	Around 1970	Operator 3.0	Seafarer 3.0
Industry 4.0	Around 2011	Shipping 4.0	Now	Operator 4.0	Seafarer 4.0(E-farer / Operator 4.0)

through different revolutions and is now entering into Maritime 4.0. Subsequently, shipping industry, as a subset of the maritime industry, has been through Shipping 1.0, Shipping 2.0, Shipping 3.0, and recently the Shipping 4.0 by imagining the future autonomous shipping. Additionally, the technological aspect of industrial revolutions was always the focus of all industries development, while the human cognitive element has been neglected. This factor is highlighted in Industry 4.0 and subsequently shipping 4.0.

INDUSTRY 4.0 AND MARITIME INDUSTRY

The primary purpose of Forth Industrial Revolution is to strengthen machines to adapt, communicate, collaborate, and fix each other on an industrial scale. Powered by digitalization and driven by data, Industry 4.0 aims to deploy machine learning algorithms to reduce human intervention in the work processes. This process has changed the work place and redefined the jobs in an unprecedented way. As the result the role of human operator has evolved analogously.

In the past few decades, the maritime industry witnessed a series of technological transformations. Digitalization is employed through e-navigation to increase efficiency in ship operation and safety. Introducing digital equipment such as AIS, ECDIS, and automation in ship's machinery and navigation transformed the ship operation. Digitalization and Industry 4.0 technology development in areas such as the Internet of Things (IoT), Artificial Intelligence (AI), automation, and blockchain created new opportunities in the maritime industry. This development process in the shipping industry requires all sectors including the port, ship, and manning sectors to connect to grow simultaneously to reach the full capability. This gradual transformation process can be considered as a challenge but importantly as an opportunity for more connectivity in shipping industry. The advance connectivity paves the way for introduction of autonomous shipping. Likewise, the seafaring had to evolve to respond to these changes by going through parallel revolutions. Table 1 presents the alignment of industrial revolution with shipping, operators, and seafarers' revolutions.

COGNITIVE HUMAN FACTOR IN INDUSTRY 4.0: THE CASE OF SHIPPING INDUSTRY

As discussed, the main driver of Industry 4.0 is digitalization and automation. The technology rich workplace will redefine the human - machine work division. This will redefine the role of human in the novel workplace with the consequence of required new competency and skills for their operators.

The shipping industry in turn is experiencing radical changes through Industry 4.0 implementation. The Shipping 4.0 digitalized and automated ships radically have changed the human-machine interaction, skilled performance, mental workload, decision-making, and training and education of seafarers. Consequently, seafarers will experience new job definition and the new training requirements for ship operation (Emad, 2020, p. 1). Thus, seafarers are expected to be digitally inclined to be able to align and update their skills based on the technological advancement in the shipping industry. Although shipping 4.0 is automating many of the jobs historically performed by human however, seafarers will remain an essential part of ship operation either on board or on Shore Control Center (SCS).

FROM OPERATOR 4.0 TO SEAFARER 4.0

Throughout different industrial revolutions the role of humans as operators have gradually evolved. To understand the difference between human role in different industrial revolution, Table 2 compares the operators revolution in industries with the seafarers' revolution in shipping. As it illustrates the progressive introduction of technology gradually move the human as the sole performer to smart monitoring and collaborator with machines. The human element with introduction of each revolution gradually moves from foreground to background leaving the machine to perform the jobs.

The Operator 4.0 and Seafarer 4.0 play as smart agent in an intelligent environment in smart factories or smart ships. The Operator 4.0 by benefiting from Industry 4.0 technologies needs to define a frame of work that utilizes advanced technology that provides real-time access to large amounts of data and information that allows monitoring and collaboration with automated systems.

FUSION OF TECHNOLOGY AND HUMAN FACTOR

Operator 4.0 implies cognitive interaction that highlighted the specific degree of human-technology coexistence with the aim of enhancing the human's physical and cognitive capabilities (Thorvald, Fast Berglund, & Romero, 2021). In this respect, according to Table 2, Operator 4.0, synonymously used as Seafarer 4.0, emphasizes that how Seafarer 4.0 can follow the same structure as Operator 4.0. Accordingly, the Seafarer 4.0 should become an operator that predicts the ship's situation and makes a real-time decision through constant cognitive interaction with robots, databases, and other ships. Thus, Seafarer 4.0 as a kind of Operator 4.0 should be able to use available technological capability including virtual reality (VR), augmented

Table 2. Human element in industrial revolution context. (Shahbakhsh et al., 2021) (Romero et al., 2016).

Operator Revolution	Features	Seafarer Revolution	Features
Operator 1.0	Performing manual and skilled work with mechanical tools support	Seafarer 1.0	Ship operation through star, moon, and sun
Operator 2.0	Performing assisted work with computer tools support like CNC machine	Seafarer 2.0	Ship operation through power
Operator 3.0 (Human-robot collaboration)	Performing cooperative work with machines, robots, and computer tools support	Seafarer 3.0	Ship operation through an automatic navigation system
Operator 4.0 / (Operator of future) / (Human-automation symbiosis)	Smart and skilled operators who performing work aided by machines	Seafarer 4.0 (Efarer / Operator 4.0)	Unmanned and autonomous ship management through digital technologies (digital competencies)

reality (AR), artificial intelligence (AI), and other emerging technologies to manage cognitive interaction.

Seafarer 4.0 in the context of the digital and autonomous platforms requires a smart interaction with machines rather than simple physical interaction. This emphasizes the importance of future seafarers' cognitive skills and capability. Therefore, it will place the human role in the spotlight alongside and asks for the humans to possess a higher level of digital competency. Thus, the workplace will turn into a CPS based activities that put machines (physical process), technology (cyberspace), and seafarer (human operator) in the loop to work and collaborate. In this regard, the Human Cyber-Physical System (HCPS) term emerged. Human-CPS is defined as "the improvement of human ability for dynamic interaction with machines in the cyber and physical world and simultaneously human physical improvement including sensing and cognitive ability by wearable devices" (Romero et al., 2016, p. 3). Therefore, digitalization and automation require Seafarer 4.0 to become part of HCPS to perform diverse roles and responsibilities on the autonomous ship and shore control center (SCC). This requires seafarers to have machines and robot interaction in cyber platform to achieve a human-automation symbiosis work platform. Table 3 summarizes the Human-CPS architecture level between human element and CPS element and gives a simple understating of how this system performs.

Table 3 displays standard components of human cognition and machine intelligence. For instance, for all five sections, machines perform more

Table 3. Human Cyber-Physical Systems architecture levels. (Flores, Xu, & Lu, 2020).

Human Element	Human-CPS	CPS Element
Body action	Configuration (Executing)	Controller, actuators, networks
Experience, emotion, intelligence	Cognition (Prioritizing)	Program, graphic, interface
Memory and intellect	Cyber (Comparing)	Algorithms, models
Memory and intellect	Conversation (Analyzing)	Program, algorithms
Five cognitive senses	Connection (Sensing)	Sensors, server, networks

precisely and professionally compared to humans. Accordingly, Seafarer 4.0 can benefit from the CPS and combined that with operators' job definition and become Human-CPS. The HCPS initiated from the traditional human-physical system (HPS) and then matured to HCPS in industry 4.0. It is estimated that HCPS will progress through Industry 4.0 full digitalization and automation and becomes part of Industry 5.0. Industry 5.0 with a human-centric approach picture a symbiosis between intelligent humans and machines.

Accordingly, for the successful implementation of Seafarer 4.0 to encompass HCPS, the shipping industry needs constant training for its workforce to be able to utilize the new technologies and tools in the complex workplace. Indeed, the education process including reskilling and upskilling for the current workplace based on the technological progress has paved the way for seafarers to take advantage of recent progress in digitalization and automation as an assistant to increase their physical, sensory, and cognitive capabilities.

EDUCATIONAL NEEDS AS A RESPONSE TO DIGITALIZATION CHALLENGES

In response to digitalization challenges that lead to a new role and responsibility and following new educational requirements, the maritime education and training system seems to require a massive change in the way of training of its workforce. The progress of digitalization and automation will construct a direct impact on the nature of work at sea and in on shore. Thus, there is a need for a massive investment in education program as the same level of technology embracement in maritime industry. Since the shipping industry is an international industry, all training programs and competency requirements need to be regulated internationally by IMO. In this respect, the Maritime Education and Training Institutes (METs) has the massive responsibility to train current seafarers to become Seafarer 4.0 as a kind of HCPS. In this regard, the maritime training institutes can take advantage of Industry 4.0 technologies by utilizing E-learning and B-learning facilities to meet the lifelong learning policy.

The educational response to continuous changes can categorize into new training plans, re-skilling programs, and up-skilling processes for the current

workforce to address the ongoing workplace changes and make digital competency a critical element. Moreover interestingly, for recognition of future training needs, the shipping industry can take the benefit of cognitive abilities tests (CATs) to recognize and measure the future seafarers' mental skill demands and cognitive skills that are required to perform a task onboard or on shore control centers (SCS).

In addition to educational requirements of new generation of seafarers, the maritime education providers face two type of challenges that categorized into general impacts of Industry 4.0 technology on education and the second one is specifically related to the digitalization and introduction of autonomous shipping. It highlighted the point that any changes in technology and even regulation in shipping will lead to emergence of new job, roles, and maritime education and training systems. Moreover, the other discussable point is related to the speed of changes in shipping industry under current revolution that is not tolerable. This specific challenge requires the constant development of human cognitive factor in areas of human-machine interaction, skilled performance, mental workload, decision-making, and training and education.

More importantly, the full implementation of Seafarer 4.0 in the shipping industry performs as a flow to connect Industry 4.0 to the next revolution, Industry 5.0, by emphasizing the centric role of humans in all industries. Industry 4.0 is a technological revolution brought tools and technologies to make a complex and professional workplace with requirement of skilled human factor. However, the Industry 4.0 is seeking to reduce human role in system but this a weakness of this revolution that does not have a focus on the human factor. Thus, there is a critical need for another revolution to get back human-centric role in the system (Shahbakhsh et al., 2021). Thus, to achieve the balance among human and intelligent systems interaction, the constant training of seafarers under technological development criteria is required by regulating a new training regime by IMO and other related stakeholders.

CONCLUSION

The present study confirms how the digitalization and fusion of Industry 4.0 technologies among industries' physical and digital world is making another level of expectation on the human cognitive element that has not been sufficiently addressed. Although, the research is centered around the technological development however, the role of human in the revolutionary movement in shipping industry is yet to be investigated. Accordingly, it is evident that there is a considerable gap between the skills and expertise of the future and the current maritime workforce to cohesively share control in the autonomous ship with machines. Therefore, there is a requirement for the shipping industry to make a strategic roadmap and plan for developing cognitive human factors through training in advance toward a more intelligent and autonomous workplace. Parallel to the digitalization progress in the shipping industry, the key stakeholders should start to decode the training program for its seafarers in different areas to find the gaps and make new training programs to exercise the Human-CPS an autonomous platform. To conclude,

the present study has defined a picture of digitalization disruptive challenges in the shipping industry with the cognitive human factors. It illustrates how seafarers as a human factor have experienced a different level of cognitive challenges through time and now is transforming to Seafarer 4.0. Therefore, comprehensive research regarding seafarers' training need and challenges for autonomous shipping operation in the digitalized era is required.

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