A new educational model for Marine 4.0 technologies

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Synopsis

The fourth industrial revolution, "Marine 4.0", has brought the digitalization era in marine operations and the introduction of new and sophisticated technologies that can enhance the management and operation of the vessels, up to a level where vessels can be operated totally unmanned. One of the gaps when introducing new technologies is the education of the operators on board, that have to be aware not only how to operate the systems, but also the potential risks involved with these technologies. The traditional educational model based on technical knowledge only may not be adequate to the new requirements, with concrete risks that operators are unable to understand and use these technologies in full. The Italian Maritime Academy has studied this issue and proposed an educational model to fill this gap, especially addressed to the next generation of deck and engine cadets. The educational model is divided into modules, that include marine processes knowledge, sustainability, digital technologies (hard skills), risk analysis and a specific module dedicated to soft skills focused on problem-solving, teamwork, communication, leadership, conflict management, and situational awareness. The goal is to educate cadets to be ready to operate on any type of vessel according to the four degrees of autonomy defined by the IMO Marine Autonomous Surface Ship (MASS) provisions. This paper will describe the educational model proposed by the Italian Maritime Academy for training the new generation of operators on board these technologies, which includes not only technical skills but also skills like problem-solving, effective communication, teamwork, and others to ensure that benefits and risks are properly known and managed.

Keywords: Marine 4.0, Education, Training, Seafarers, Hard skills, Soft skills,

1. Introduction

There have been significant revolutions in the marine industry over the last centuries that have had a significant impact on ship design and operation. Henrik Gronlund [1] and others identify four milestones of this revolution: the first revolution, Marine 1.0, has been at the end of the 18th century with the era of steamships replacing sailships. Marine 2.0 corresponds to the mass production of ships by USA shipyards in 1940 or, according to other sources, to the introduction of the diesel engine as propulsion (1912). The development of the modern intermodal shipping container, which revolutionized transport and international trade in the second half of the twentieth century, represents the start of the Marine 3.0 era. The last revolution Marine 4.0, which started in the first decade of this century, is digitalization that is. According to Gartner digitalization is "*the use of digital technologies to change a business model and provide new revenue and value-producing opportunities"* [2]. Digitalization, in the marine industry, is the combination of real-time data and powerful digital processing, with the purpose to develop systems and solutions to enhance operational safety and reduce the lifecycle cost, and the environmental impact of the ships.

Examples of these new solutions are intelligent situational awareness systems using sensors like radars, night vision cameras, and lasers to improve the decision support during manoeuvring and condition-based maintenance systems of equipment using remote diagnostics. Further developments are in the direction of autonomous ships, able to undertake decisions and determine actions with little or no human interaction The digitalization process has not only affected the design of the ship and on board equipment. The human element and education are other key factors for the successful implementation and use of this technology.

The Italian Maritime Academy has studied this issue and developed a new educational model for the next generation of deck and engine cadets. This model combines the technical subject of study (*hard skills)* with other competencies that include the ability to communicate with others, to solve problems, to manage stressful situations, to work as a team, and others. These competencies are called *soft skills* and can be used in any aspect of the job.

The paper discusses the applications of these new technologies in the marine industry; the development of autonomous ships and their impact on international regulations; the requirements of new skills by the next

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generation of "cyber-seafarers" and the new proposed educational model; and the need of an integrated approach to marine education.

2. Marine 4.0 and the emerging technologies

Digitalization has brought innovative technologies and a wide area of functions that can be implemented on board ships. Table 1 below provides a description of the digitalization technologies and their main applications:

Technology	Aspect	Applications
Internet of things	System of interrelated, internet-connected objects that can collect and transfer data over a wireless network without human intervention	• Asset management (predictive maintenance) • Energy saving • Passengers cabins management • Cargo control (containers)
Big data	Can be defined as a large volume, variety, and speed of information growing at ever-increasing rates, and requiring data analytics to correlate the multitude of information to draw useful conclusions	• Energy saving (optimum speed operation) • Environmental parameters monitoring • Hull and propeller cleaning • Design optimization • Voyage planning • Safety of operations
Artificial Intelligence	Using computers to perform tasks that traditionally require human intelligence. This means creating algorithms to classify, analyse, and draw predictions from data. It also involves *acting* on data, *learning* from new data, and *improving* over time.	• Route planning and hazard avoidance • Cargo monitoring and tracking • Ship performance forecasting • Port operations optimization
Augmented reality	The real-time use of information in the form of text, graphics, audio, and other virtual enhancements is integrated with real-world objects and presented using a head-mounted-type display or projected graphics overlays.	• Training simulators • Decision support systems • Situational awareness
Vertical and horizontal integration	A system is defined as vertically integrated if it manages to involve more subjects, starting from the field level up to the fleet management level. Horizontal integration is data exchange and allows for seamless systems and information integration at the same level: sensors, automation, control, etc.	• Integrated Ship Management System
Blockchain	Blockchain technology enables distributed public ledgers that hold immutable data in a secure and encrypted way and ensure that transactions can never be altered.	• Financial transactions • Contracts • Ownership registries • Supply chains and logistics • Notary services • Identity services

Table 1 Marine applications of digitalization

Significant examples of these technologies are the intelligent assisted docking of ships based on artificial intelligence algorithms using own and other vessels position information to calculate a collision free trajectory to the selected docking locations; efficient electric power and electrical consumption optimization based on big data analysis; and blockchain to track the paper trail of millions of shipping containers across the world.

3. The autonomous ship development and the impact on marine regulations

The concept of autonomous ships was first introduced last century (1970) in Rolf Schonknecht's book "Ships and Shipping of Tomorrow" which mentioned that in the future the captains will perform their duties from an onshore office building and the vessels will be navigated with the use of computers. Japan implemented a project of an intelligent ship from 1983 to 1986, to develop highly automated systems integrating marine and harbour operations without any interaction by the crew on board and receive support from a shore-based system, which is linked through satellites. Autonomous ship operation became of interest to research institutes and marine industries during the first decade of the new century and several projects were launched, supported by Government Organizations, among them:

- The Korea Autonomous Unmanned Surface Vessels for maritime survey and surveillance by the Korea Research Institute of Ship & Ocean Engineering (KRISO), sponsored by the Ministry of Oceans and Fisheries (2011).
- The EU project – Maritime Unmanned Navigation through Intelligence in Networks (MUNIN), is funded by the European Commission under its Seventh Framework Programme (FP7). This project intended to investigate unmanned ships' technical, economic, and legal feasibility. MUNIN's concept was to develop an autonomous ship, guided by automated on-board decision systems but controlled by a remote operator in a shore-based control station (2012 – 2015). [3]
- ReVolt project, a new concept for zero-emission unmanned ships for short voyages with battery power launched by DNV – GL. The size of the ship is approximately 1,800 dwt and 100 TEU capacity container ship. A scale model based on this concept is now being used by students at NTNU in Trondheim for testing autonomy and remote control functions (2013-2018).
- Advanced Autonomous Waterborne Applications Initiative (AAWA) was launched by Rolls-Royce to analyse challenges related to autonomous shipping operations in different fields. It developed both autonomous and remote operations for ship navigation, propulsion, and all onboard technical systems. Other partners that participated in this project are DNV GL, NAPA, Deltamarin, Inmarsat, and Finnish Research Institutes and Universities. [4]

The outcome of these projects was new and advanced solutions focused on improving the safety and performance of autonomous vessels and not only, as "conventional" manned ships could also benefit from these solutions (the so-called "smart ships"). Examples of this are intelligent awareness based on sensors fusion of LIDAR and short-range radars, night vision infrared cameras and other sensors, or decision support systems based on machine learning to understand a specific operating scenario based on information provided from situational awareness systems to decide a safe route and avoid collisions. A further example is the health monitoring of machinery by remote diagnostics of data from sensors installed on machinery and equipment.

Any modern technology that involves safety, security, and the environment has an impact on international rules and regulations, and already in 1964, the International Maritime Organization (IMO) discussed an innovative technology that was rapidly changing ship operation and called "Automation". At the 8th session, the Maritime Safety Committee (MSC) introduced the basics, starting with a definition of automation: "*automation refers to those processes in which machines – often including electronics control – adjust and control their performance with little or no human intervention once the operation is started. A distinction is made between a fully automated system, a partly automated system, and remote control.".* A few decades later, in 2017, a comparable situation occurred, when the MSC of IMO decided to integrate the new rapidly evolving technologies of autonomous ships into a regulatory framework, to balance the benefits against safety, security, and environmental concerns. Automation and autonomy are two different concepts, however, both cases needed a regulatory approach. A regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS) was initiated in 2017, and it was finalized at the 103rd session of the IMO MSC in July 2021. The final document considered four different levels of autonomy, among other important issues, as shown in Table 2 below. Last April the 105th session of MSC approved a road map containing a work plan for the development of a goal-based instrument, in the form of a non-mandatory Code, with a view to adoption in 2024 as the first stage. Based on the experience from the application of the non-mandatory Code, a mandatory MASS Code will be developed which is envisaged to enter into force on 1 January 2028. This mandatory Code will be a new instrument; however, SOLAS and other regulations will be amended to ensure correct implementation.

MASS DEGREE 1	MASS DEGREE 2	MASS DEGREE 3	MASS DEGREE 4
• ***Ship with automated processes and decision support.*** • Some operations are automated and at times be unsupervised but with seafarers onboard ready to take control. • Seafarers are onboard.	• ***Remotely controlled ship with seafarers on board.*** • The ship is controlled from a remote location. seafarers are available onboard to take control and to operate the shipboard systems and functions. • Seafarers are onboard.	• ***Remotely controlled ship without seafarers onboard.*** • The ship is controlled and operated from a remote location. • There are not seafarers onboard.	• ***Fully autonomous*** • The operating system of the ship is able to make decisions and determines actions by itself.. • There are not seafarers onboard.

Table 2 The MASS degrees according to IMO

4. New skills requirements of cyber-seafarers

The role of seafarers is changing at the same rate as the development of new technologies and there is more focus on human element implications. The human element is present in autonomous vessels, including those unmanned and it has been shifted from ship operation to the design, building, and testing of the technical systems of the ship. N. Leveson expressed this concept by stating that "removing dependence on an operator by installing an automatic device to take over the operator's function only shifts that dependence onto the humans who design, install, test, and maintain the automatic equipment – who also make mistakes (1995)" [5], as quoted by S. Ahvenjärvi in his paper "The human element and autonomous ship" (2006). [6]

Industries and regulatory frameworks have more concentrated on providing data and rules, but with little attention to how the data are processed and used. In many cases, industries lack a *"ship-as-a-system"* view when developing and implementing modern technologies that are seen as a tool to perform a specific function but without consideration of how they integrate with the other systems on board. The same concept applies to manufacturers' training courses, where the programs are too often written by professionals with limited or no job experience at sea. The result is a lack of the necessary knowledge of using innovative technologies and understanding their potential benefits. The MASS mandatory Code and Standard for Training, Certification, and Watchkeeping (STCW) Convention should include at least the requirements for both educational and training levels in their future works and be based on a *continuous learning* approach. Today, the proposal for the development of provisions on cybersecurity-related training for seafarers discussed by the 8th Session of the Sub-Committee on Human Element, Training, and Watchkeeping is one of the initiatives in progress. The situation does not improve at secondary schools (Nautical Institutes) or Universities where the study plan does not include any reference to the new technologies.

In a recent poll taken at the Italian Maritime Academy, junior engine cadets were asked to rank the top ten skills they consider to be their learning priorities. The results from the poll are listed in Fig. 1.

Figure 1 Top ten skills by seafarers

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Based on the current learning programs, it was clear that a new training model for cadets should be developed with the following goals:

- Fill the knowledge gap in innovative technologies
- Emphasize the importance of information and data
- Learn how vessel operation and safety are affected by the new technologies
- Identify the potential failures and criticalities of the systems (risk analysis)
- Understand how to manage an emergency

The training models used in other industries such as aviation, container cranes, subway transits, and others have been analysed as references to achieve the most effective model for the specific context of use. One important outcome of this analysis is that excessive reliance on automation distance the operator from the process to a level where he might be unable to take manual control in case of failure to the automatic control. This is also called *"clumsy automation"* and the consequence is a skill degradation of the operator in the long term.

5. An educational model for "cyber-seafarers"

The educational scheme developed by the Italian Maritime Academy is shown in the triangle diagram in Fig. 2. The three main modules of the educational program are:

- Sustainability
- Hard skills
- Soft skills

The quantity and variety of information provided to the students are quite extensive, therefore new methods have been studied to ensure successful learning of the various subjects of study. The "learn to learn[1]" approach has proven to be the most effective method of achieving the expected results. The subjects of each module are summarised below and refer to the education of assistant engineer officers.

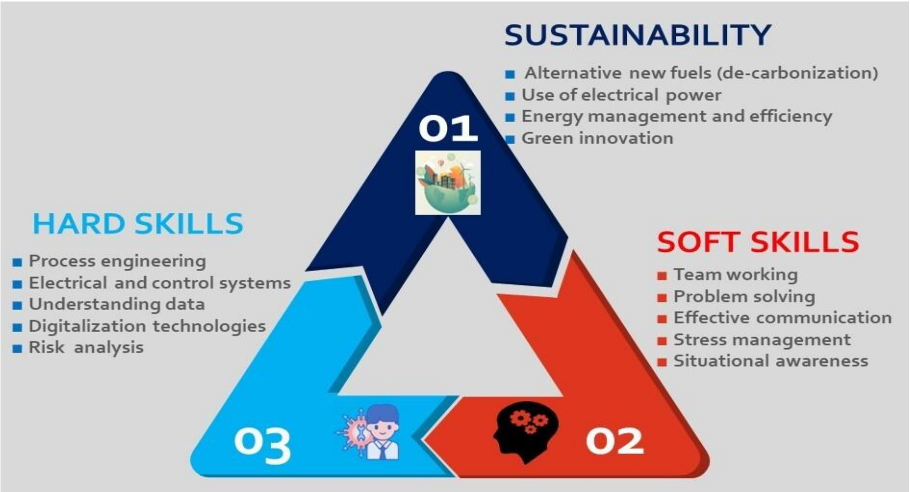

Figure 2 The triangle diagram of skills

5,1 Sustainability

The sustainability module contains the following topics and contributes to the goals of sustainability and hard skills.

- Environmental impact of the vessels and the decarbonization process
- Current international and national regulations to prevent pollution of air and sea
- Technologies to support a greener marine environment (ballast water management systems, scrubber systems, NO_x reduction methods, paintings, etc.)
- LNG (IGF code) and other alternative fuels, including batteries, fuel cells, and solar power
- Fuel efficiency measures (EEDI. SEEMP and EEXI) and energy management systems to reduce fuel oil consumption

[1] "Learn to learn" is the ability to pursue and organise own learning including time and information management, both individual and in groups.

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5.2 Hard skills

The hard skills module contains the following subjects and contributes to the knowledge of innovative technologies.

- Ship systems design and operation with a special focus on the use of electricity on board for propulsion and other auxiliary services (e.g., frequency converters application for speed control of motors), hybrid systems solutions, etc.
- Open Technology (OT) and Information Technology (IT) systems, their integration and application on board ships (see Fig. 3).

Figure 3 Open Technology and Information Technology systems

- Marine 4.0 technologies applications.
  The learning approach is based on the analysis of applications based on Marine 4.0 technologies.
  These technologies are data-centric, therefore relying on a large amount of data. Understanding the meaning of data, and how they are collected (sensors), stored, validated, and analysed using techniques such as Artificial Intelligence (Machine Learning), the Internet of Things, cloud computing, and big data are the subject of study.
  The application example is used as a case study in Health Management and Predictive Maintenance system (see Fig. 4).

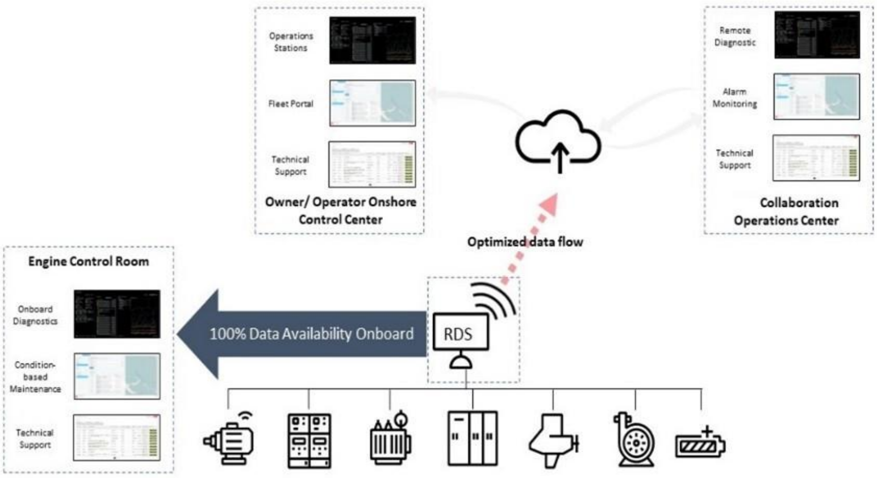

Figure 4 Health management and predictive maintenance

- Cybersecurity
  Cybersecurity is not simply a collection of procedures, but a kind of culture that drives our way of working when dealing with IT systems. The learning approach is based on IMO Guidelines on Maritime Cyber Risk Management (MSC-FAL.1/Circ.3 of July 2017) and other best practices from BIMCO, CLIA, ICS, INTERCARGO, INTERTANKO, and ISO/IEC 27001. The learning program includes:

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- Explanation of the three basic requirements for a cyber-safe ship: integrity, inviolability, and traceability.
- Cyber risk management: roles and responsibilities (Identify); risk control (Protect); timely identification (Detect); system restoration (Respond), and recover (Back up)

- Risk management

  Systems and equipment failures and human errors are the three hazard potentials that are studied in terms of risk assessment and risk analysis.

  The program module includes:

  a) Risk and hazard definition
  b) Risk assessment and analysis
  c) Failure Mode and Effect Analysis (FMEA)
  d) Potential risks and consequences from systems and equipment failures installed onboard
  e) Redundancy, availability, and fault tolerance
  f) How to manage an emergency from real cases analysis

5.3 Soft skills

Soft skills are not related to specific technical jobs or roles; they are general characteristics that can help seafarers in specific tasks e.g., working in a team. According to published research about maritime jobs, they can be defined as “a cluster of qualities, habits, personality traits, attitudes, and social graces”.
Among the different soft skills, the following have been identified as important to learn by the students:

- Teamwork
- Problem-solving
- Conflict management
- Communication
- Leadership

As an example, the problem-solving strategy is based on the seven steps model by Giorgio Nardone, a psychologist who specialized at the Mental Research Institute in Palo Alto (California). His approach to problem-solving is shown in Fig. 5.

Figure 5 The seven steps of problem-solving

In addition, a training session has been dedicated to situational awareness. Situational awareness (SA) is how one pays attention to the surroundings and the way one processes elements in a situation to make informed decisions. Situational awareness is the tool to avoid accidents and disasters and involves the ability to project future events based on your situation. The training model is based on three skill sets: perceiving as the ability to gather information from various displays around, comprehension as the capability to understand and analyse the data, and perception as the capacity to predict potential outcomes from the use of information. The target of SA training is to support the future “cyber-seafarers” in better decision-making and fewer human errors.

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6. An integrated marine educational approach

Training and education of the next generation of "cyber-seafarers" are critical issues that require a holistic approach. Technical colleges and universities cannot be the only institutions responsible for providing training from basic levels to skill levels, mainly for reasons of resources and experience. The strategy has to be that of an integrated system, where academy, industry, shipowners and, possibly, classification societies cooperate to develop the most suitable educational model, matching the operational and safety requirements for the "cyber-seafarers.", regardless of whether they operate on board or ashore and the autonomy level of the vessel.
The firm points of this model are:

- Use of full-scale simulators based on the latest digital technologies (virtual and augmented reality, artificial intelligence, etc.) is essential for an all-around education. Simulation not only enhances the knowledge and competence of systems technologies and their applications, but it can be used also to train operators on team working, situational awareness, decision making, and how to interact in safety-critical situations.
- Self-assessment and continuous, lifelong training programs have to be included in IMO STCW Convention to ensure that seafarers are updated with existing and new technology developments.
- Job rotations of seafarers from on board to ashore employment positions can be a good method for acquiring those transversal skills that reflect the changes in the marine industry, such as maritime laws and insurances, ship finance, ports and logistic chain, and ship management. Industries can also benefit from this mobility by having on-hand feedback from systems operational experience, which can be useful to introduce design improvements.
- "Train the trainer" is another important issue to be addressed. The new technologies require a wide range of hard and soft skills and specialized trainers for each discipline will be required to work as a team, to educate the seafarers on their proper use and the limits. A specific experience from field applications by the trainers will be certainly a plus.

Digitalization is a process that develops rapidly and if the cluster industry, shipowners, academia, and regulatory bodies will not adapt the training schemes at the same speed, the benefits of the technologies risk to be not as expected.

7. Conclusions

This paper describes how digital technologies offer an excellent opportunity to improve the safety and efficiency of ships to an unprecedented level and which skills will be necessary for future officers and engineers.
The Italian Maritime Academy has studied the implications that these innovative technologies have on the education and training requirements of next generation officers and engineers and has proposed a new educational model based on three different topics:

- Sustainability or understanding how to reduce the environmental impact of ships.
- Hard skills that include the knowledge of modern technology features and their functions.
- Soft skills that are not related to technical competencies but can help operators to perform specific tasks such as problem solving, teamwork, communication, etc.
- Cybersecurity and risk management are other important parts of this education process

The final goal is to educate the next generation of *cyber-seafarers* that can competently operate future ships, regardless of the autonomy level, including remote operation from a shore based control centre.

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