# Simulator as a Critical Training Tool for Autonomous Ship Operators

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**Abstract**

In the era of Industry 4.0, the maritime industry is going through a profound evolution by introducing smart and autonomous shipping. This evolution is driven by advanced technologies such as the Internet of Things (IoT), Additive Manufacturing (AM), Artificial Intelligence (AI), and more importantly, Virtualization, including digital twin and simulation. Indeed, the implementation of these technologies and their transformative nature has changed the environment of workplace onboard ship and ashore, requiring the new and innovative training tools and systems. As defined by the International Maritime Organization (IMO), the shift from traditional shipping to autonomous shipping will take through four degrees. In this classification, as the ships progress to degrees two and three, seafarers/operators require to be trained for the skills and competencies that enable them to remotely work with advanced systems and intelligent machines through a Remote Operation Center (ROC). These novel workplaces onboard ships and ashore accordingly are redefining new training tools and programs for seafarers. Simulators as a central and indispensable component in training systems from past to present has the capability to make a paradigm shift, bridging the gap between traditional onboard training and the SCC training environment to meet the autonomous ship operation requirements for seafarers. This paper represents part of result of an IAMU-funded qualitative study on simulation training programs for future autonomous ship operators. The research highlights the critical role of advanced simulators in training the next generation of seafarers/operators and strongly recommends the gradual shift from onboard training to simulator training.

**Background**

The Fourth Industrial Revolution is reinventing all industries. The main driver of Industry 4.0 is the digitalization and automation (Shahbakhsh, Emad, & Cahoon, 2021). Like other industries, the shipping industry has gradually embraced the Industry 4.0 framework and technologies with the result of the introduction of autonomous and unmanned ships (Emad & Shahbakhsh, 2022). IMO has proposed four degrees of autonomy to facilitate and outline the shift from traditional shipping to autonomous shipping. The IMO degrees of autonomy represent how the seafarers' roles and responsibilities with the deployment of advanced technologies onboard ship will alter (Emad & Ghosh, 2023). An ROC is a control center/room where an ROC operator remotely monitors and controls one or more MASS ships and if necessary intervene. Even for the degree 2 of MASS where seafarers are still on board, the ROC's operators' roles in collaboration with seafarers onboard in the case of emergency and other dangerous or critical circumstances would be immense. The progress of ROC design, equipment, and functions depends on the Degree of MASS and the level of automation of the ship. Thus, the operator's role and level of human-machine interaction will change as workplaces gradually transfer from onboard ship to the ROC (Emad, Khabir, & Shahbakhsh, 2020). Therefore, the maritime education system needs new and non-traditional programs and facilities to make the operators ready for future shipping operations (Emad, Enshaei, & Ghosh, 2021). Here the simulators can play an essential role during the transition phase.

From its inception simulators always had a fundamental role in training systems of the maritime, aerospace, aviation, and forestry industries. Although has its roots in Industry 3.0, simulation matures with virtualization as one of the main Industry 4.0 technologies (Gunal, 2019). The Maritime Education and Training Institutes (MET) first began the utilization of simulators in the training of passage and route planning in 1950. However, the simulator is currently used extensively for different training purposes for pilots, offshore operations, engine control, crane operation, and vessel traffic services (VTS) training. The Standard of Training, Certification and Watchkeeping for Seafarers (STCW) convention has regulated simulator use in the MET.

Additionally, the new generation of training simulators employ technologies such as augmented reality and virtual reality (AR/VR) to provide immersive experiences and better human-machine interaction. Virtualization employs AR/VR, CPS, cloud computing, and IoT, to construct digital twins for seamless human-machine interaction (Chen, at.al. 2023; Emad & Kataria, 2022). The digital twin is a virtual model of a physical system. It is a simulation system with the variable input from a physical entity such as a ship or part of a system, for example, the ship's engine. The future simulators and digital twins will be used by seafarers to operate the ship and perform different tasks such as navigation and maintenance (Sellberg, 2017). Whilst the digital twin is the future workplace of the ship operators, it will provide an unparalleled opportunity for the training providers to replicate the digital twin of the actual ship for the benefit of training seafarers of the future. Indeed, access of future trainee seafarers/operators to these technologies in the training environment assist emerging new operators as intelligent operator to interact and collaborate with smart machines in the Industry 4.0 era (Emad, 2020; Ferreira, Armellini, & De Santa-Eulalia, 2020).

As MASS matures and seafarers' role shifts to remote operators in ROC, there will be an opportunity for maritime training institutions to use simulation/digital twin-based training models for remote ship operators. This allows for transferring a major part of onboard training to a simulation-based training (Ahvenjärvi, Lahtinen, Löytökorpi, & Marva, 2021; Emad & Shahbakhsh, 2022; Klement, 2017; Moraes, Kipper, Hackenhaar Kellermann et al., 2022).

Currently, maritime universities across the world are facing a major challenge in responding to maritime industries' needs of providing them with quality seafarers who are not only competent to work onboard ships of today but are prepared to operate the ships that need to be remotely controlled. To fill this gap the authors designed a qualitative research project titled "Simulation Training Program for the Future Autonomous Ship Operators". This project is funded for the 2022-2023 period by the Nippon Foundation through the IAMU Organizational Development Project scheme. The project investigates and tests the application of MASS simulation technology for training future seafarers. The result of this research illustrates how the technology progression helps to gradually shift onboard training to simulator training as the onboard workplace shifts from onboard ship to ROC. This paper presents part of the research findings of the project.

**Method**

This paper presents part of the outcome of a qualitative research study on a simulation training program for future autonomous ship operators. The research project has employed the Intelligent Shipping Technology Test Laboratory (ISTLAB) at SAMK University, Finland's ROC simulator. At first, the research team designed different scenarios where participants initially work with the traditional simulator. Subsequently, participants complete a scenario on the ISTLAB simulator as the replication of degree two MASS. The scenarios, through traditional and ISTLAB simulators, provided a unique testing and research platform that enabled the research team to collect and analyze data in different scenarios. In the second stage, each team divide into two groups of three participants. One group played the role of seafarers onboard the ship, and the other one played the role of seafarers at ROC. The two groups exchanged their positions and repeated the test. The data also collected from research participants from different groups of stakeholders including seafaring students, experienced seafarers, pilots, simulator instructors, maritime lecturers course coordinators, and researchers, with a diverse range of experience, rank, and age.

Participants were one-to-one interviewed after their consent by a set of standards, clear, and open-ended questions to avoid acquiescence, social desirability, and habituation biases. The semi-structured interview was conducted through online platform (Zoom application), and it was recorded with participants approval. . To analyze the recorded data set and understand the participants' experiences and behaviors, this research utilizes the thematic approach to analyze the data (Kiger & Varpio, 2020; Lune & Berg, 2017). The collected data was transcribed verbatim, and then the initial codes were extracted. In the next stage, the major codes were extracted, and a theme map was created. The researcher team rechecked the supporting data to confirm each theme's coherence and consistency with the data. Moreover, the research detailed notes and memos were reviewed for connection between themes that performed as an audit trail to support the trustworthiness of the research findings. Accordingly, the researcher labelled and named each theme to answer the identified gaps. And based on that the final report was written.

**Results**

This paper aims to illustrate one part of the research findings related to the simulator's role in training programs. The research questions for each scenario are designed to assess the participants' viewpoints and experiences on how the simulator as the training tool can be utilized in training current and future seafarers/maritime operators. Each scenario is designed to serve different purposes. The first scenario aimed to evaluate the participants' experience working with the traditional simulator and how the training through this simulator can be replaced with current onboard ship training. On the other hand, the ISTLAB scenarios aim to assess the participants' perspectives on the SCC simulator and autonomous shipping. The following sections present the summary of research findings related to participants' perspectives on how seafarers can benefit from simulator training to be ready for real-life onboard ship operations.

*Section 1: Utilizing traditional simulator*

This section's present analysis of the interview questions centered around participants' experience working with the traditional simulators and its comparison with actual ship experience. The participants were interviewed about their experience with practical elements of traditional simulator training and the possibility of its replacement with onboard ship training.

The analysis shows the critical role of the simulator in training systems in enabling seafarers/maritime operators to be prepared for different circumstances and situations onboard ships. In this regard, most participants pointed out how the current simulators are more realistic and closer to real ship experience compared to some years ago. Indeed, the fidelity of current modern simulators is progressing exponentially with the exposure of advanced technologies that provide a safe, secure, realistic practice environment for seafarers to be ready for current ships with advanced technology. Some participants mentioned that practicing with modern simulators is similar to playing video games. Additionally, the participants' viewpoints centered around how the current simulators in the maritime training institutes provide seafarers/maritime operators an opportunity to exercise unique and diverse scenarios in different operation areas with various kinds and sizes of ships. This provides an opportunity for seafarers/maritime operators to work as team members and develop confidence and also communication and leadership skills. Moreover, simulator training offers seafarers/maritime operators a valuable opportunity to prevent risks, learn from mistakes, and build up talent and experience to be ready to accept the responsibility for people's lives, cargo, and ship safety and security in real-world scenarios.

A pilot participant with 25 years of experience points out that:

> *You can create an environment in the simulator that looks almost like the real world, and that makes it more realistic and more relevant. Because it feels more like you're on a real ship, then you will perform more like you would do in reality. So, I think that's one of the most important things you can simulate if you will be stressed in a situation or how you will react in real life.*

While participants acknowledged the strength of the current modern simulator in the training system, they noted that some features of onboard ship training could not be completely replicated in the simulators. For example, navigation in ICE or the latency in command time in some specific ship size and model in these cases the simulator is not reacting precisely similar to the actual ship. Moreover, participants discussed the concept of seafaring skills and the lack of environmental factors in the simulator and seafarers' responses. In this regard, a participant as a marine project manager with 20 years of experience noted that:

> *You are still missing the kind of environmental factor and you are missing of course the tiredness that you have on board. You haven't been running watches for a week, or two or so. You are always kind of a fresh-minded when you go to a simulator.*

Participants were interviewed about replacing current simulator training with onboard ship training. According to the current STCW Convention, cadets must have a minimum of 360 days of onboard ship training to obtain the official license. Most participants acknowledged that current modern simulator training is close to real ship experience. Thus, replacing some parts of onboard training with simulator training is possible. Moreover, countries such as Finland and the Netherlands have started replacing simulator training with part of onboard ship training. All respondents mentioned that simulator training has the potential to partially replace onboard ship training. Seafarers need the combination of both training to acquire essential knowledge and expertise in a *"hybrid model"*. The hybrid model can be a combination of a simulator and onboard ship training. The research data analysis show that one year of onboard ship training has immense value considering the below factors:

- Onboard ship training can be completed on just one or two ships, while with simulator training, the seafarers can practice with different types of vessels.
- Onboard training can be completed in open sea conditions with few moorings, traffic, and environmental factors. In contrast, simulator training provides a facility to practice in congested areas with heavy traffic and different weather conditions in the safety of a simulated environment.
- One day of onboard ship training could be just nonrelated duties, while one of the simulators can be passage planning and practicing in different scenarios.

The data analysis results indicate that the one year of training onboard ship can be reduced by partly replacement with simulator training. Accordingly, combining simulator and onboard ship training can foster a unique training regime for seafarers to be familiar with and ready for real-world scenarios. This new hybrid model can facilitate the introduction of autonomous ships and SCC concepts to the current and new generations of seafarers. However, this simulator training replacement with onboard ship training requires a massive evolution that includes:

- Designing new dynamic training content and models based on the practice objectives.
- Designing and testing different scenarios based on the various weather conditions and traffic situations.
- Designing dynamic emergency situations that include mishaps such as collision, grounding, fire, etc.
- Constant deployment of new generations of technologies on simulators to authenticity level up practice
- Setting up certain hours and programs per day for simulator training to cover onboard ship training.
- Creating the standard in terms of promoting leadership, effective communication, safety, and security in the simulator to replicate the onboard ship environment and atmosphere.
- Designing advanced training scenarios and adding skilled captains and officers to the team to replicate the natural onboard ship environment and atmosphere so seafarers can engage and collaborate with the professional team members and learn and ask their questions.
- Revision of current STCW convention in alignment with changes

This part of the research outcomes indicates how deploying advanced technologies such as VR, AR, cloud computing, and AI result in simulator development. It gradually has shifted the mindset of seafarers and their trust in technologies. Moreover, the research data analysis shows how the hybrid training model could be efficient in terms of time and quality training for training current and future seafarers.

*Section 2: Working on ISTLAB simulator*

This section illustrates the result of research questions related to participants' viewpoints about ISTLAB and how this ROC simulator could help seafarers to gain knowledge about autonomous shipping.

Participants mentioned that the ISTLAB simulator is a good start for developing knowledge about the remote operation of ships. However, there is a need for constant development of authentic scenarios for ROC simulators. Most participants acknowledged that working with ISTLAB created another level of experience with advanced technologies and tools such as big screens, eye tracker glasses, cameras, and topography maps. The ROC simulator, such as ISTLAB, helps seafarers develop knowledge about autonomous ships and ROC. However, there is a critical need for continuous improvement with the deployment of Industry 4.0 advanced technologies in addition to other related factors.

In response to questions related to how many hours of the ISTLAB simulator can assist seafarers in developing enough knowledge about different factors of ROC. The data analysis indicates that the training hours depend on factors such as:

- The seafarer's learning abilities
- The seafarer's previous experience
- Availability of exercise areas
- The level of seafarer's ICT knowledge
- Validity and variety of scenarios
- How technology and technical-oriented a person is

For instance, our data shows that skilled seafarers can learn faster compared to a newcomer in the maritime industry because of previous experience and ability of visualizing of the situation in their minds that leads to making a decision and controlling a ship in real time. In contrast, some young seafarers who are experts in computer and online gaming have the minds that are aligned with the ROC concept. They are more capable of embracing technologies and the ability to control a ship remotely. Accordingly, operating a ship remotely in congested areas like rivers with high traffic and on the shore is more complex and challenging compared to open sea conditions, which require more hours of practice to develop knowledge about ROC. In this regard, one of the participants with 20 years of experience noted that:

> *It depends a lot on the background of a person. Like how technically oriented one is. Let's put it very simply if you are familiar with using a computer. You will get used to that environment very quickly. If you are not, it will take time.*

The data analysis indicate how Industry 4.0 has transformed simulator training and resulted in ROC simulators such as ISTLAB. As mentioned, the learning process for each person is different, requiring the maritime training institutes to design the course and then personalize the courses based on each group or person's experience and learning ability. However, the data indicates that the training hours with traditional simulators should increase. Along with this shift, working with SCC simulators should be added to training programs to give the seafarers/maritime operators the remote ship operation experience and to develop knowledge about autonomous ships as one of the participants with extensive experience stated *'I think there needs to be some kind of this remote operating center simulator in the schools'.*

Moreover, the data analysis outcomes illustrate that the maritime training institutes should develop courses about autonomous ships, new technologies, ICT, and the SCC concept in addition to SCC simulator implementation in the training centers. Most participants directly or indirectly highlighted the importance of the regulatory bodies, shipping companies, and training providers' collaboration to prepare seafarers for changes in response to autonomous shipping. A simulator instructor with 24 years of experience noted that:

> *There should be subjects about autonomous vessels and, of course, remote-control vessels as well. And maybe the idea for this kind of subject is what is the situation at the moment? And what are possible ways to proceed in the future?*

This section's data analysis highlighted the importance of SCC simulators for developing knowledge and skills about autonomous ships and SCC.

## Conclusion

The shipping industry is not traditional anymore. Industry 4.0 is penetrating all aspects of shipping and thus the seafarers/maritime operators need to be competent for the new roles and responsibilities resulting in new technologies and autonomous shipping. The simulator, as a critical training tool that was in the training system from Industry 3.0, is getting mature through Industry 4.0 and advanced to the next level of simulation. This new advanced simulator can be a game-changer in training systems. The data analysis results indicate that some parts of onboard training could be replaced with simulator training to benefit the shipping industry and seafarers. We suggest the *hybrid model* of training that combines onboard ship training and simulator training could help seafarers gradually shift their mindset to work with and trust advanced technologies. Moreover, the research data presents the importance of the SCC simulator in developing knowledge and experience about autonomous ships and SCC. At the same time, the training could be different based on a person's previous experience, learning ability, technology orientation, and operation areas. Accordingly, the analysis strongly suggests that the training providers should implement and utilize the SCC simulator in addition to the traditional simulator to prepare seafarers for the concept of autonomous ships and SCC.

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