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Met Enhancement Using Modern Simulation Technologies: Xr, Web and Full Mission

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ABSTRACT

Modern maritime education relies heavily on simulator training to prepare students for complex and dynamic maritime operations. This article explores the recent advances in ship handling simulation and training in the contemporary context. It focuses on the application of cutting-edge technologies such as extended reality (XR) and computer-based simulations, as well as the incorporation of realistic data and scenarios into training programs. It also considers the challenges and opportunities of adopting these technologies in maritime education and training (MET), and their potential implications for the industry. The article provides a comprehensive overview of the current situation of simulations and training for different maritime operations and demonstrates how these technologies can improve safety, efficiency, and performance in the maritime industry. User feedback on the VR implementation is presented and discussed based on the VR simulators provided. The article also proposes the concept of a multi-station ship handling VR simulator for further development and enhancement.

1. Introduction.

The intense nature of globalization has led to an increase in the demand for economic and environmental efficiency in maritime transport, resulting in a rise in the volume of goods transported at reduced costs. According to the United Nations Conference on Trade and Development (UNCTAD) Review of Maritime Transport [1], maritime trade has mostly shown a positive trend over the past decade, with rates ranging from 0.5 to 4.8%. However, due to the COVID-19 pandemic in 2020, which disrupted the global economy and affected supply, demand, and logistics, maritime trade decreased by 3.8%. In contrast, global merchandise trade increased by 4.3% in 2021, resulting in additional port congestion and reduced levels of service and reliability. The global commercial fleet also grew by 3% that year, with a total of 99,800 ships, increasing the demand for jobs in the maritime sector.

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As a result of this increase in employment demand across various economic activities, having a sufficient number of qualified seafarers has become crucial for the proper functioning of the maritime industry. Seafarers must constantly meet growing requirements and regulations regarding training, certification, and maritime safety. They play a key role in ensuring the safety of ship operations in a global and multicultural environment and perform various responsibilities worldwide. Therefore, maritime professions are regulated globally in accordance with relevant international agreements. The International Maritime Organization (IMO) cooperates with the International Labor Organization (ILO) to establish a regulatory framework for the education, training, professional qualifications, working conditions, and safety of seafarers.

In this context, advanced technologies such as extended reality (XR) and computer-based simulations, which are very apt for maritime education and training, should be given special attention. XR applications in training are mostly used for industrial and emergency preparedness, as well as healthcare, firefighting, and other similar fields [2]. XR training has shown positive results in various domains, such as fire safety [3], industrial machinery [4], rehabilitation [5], and surgery [6, 7].

The maritime sector has also contributed to XR, with efforts among ship classification societies (Lloyd's Register), maritime start-ups (Immerse) [8], and maritime education and training (Crane Certification Association of America, Onebonsai). Limitations of the present MET methods, such as resources, educational content, time, and safety are highlighted in [9]. In this way, research on the comparison of VR and simulator-based maritime training efficiency was conducted in [10]. Despite the results stating more immersion when steering a ship by sight, the ship behavior model had a lack of accuracy. Ergonomic factors, particularly workplace design proposals for ships' bridges using VR-reconstructed operation scenarios, are discussed in the study [11]. However, the mentioned concept does not consider spatial awareness based on the prescribed role in the scenario. The architecture of an application for real-time AR navigation in inland and coastal waters to increase the safety of sailing, where sailors can become part of the data acquisition process is proposed in the research [12]. Although performed tests approved the efficiency of AR for content presentation in the navigation process, the application considered is not aimed to improve professional skills of seafarers. Several types of research carried out in [13-15] resulted in the implementation of the term Immersive Safe Ocean Technologies (ISOT), which involves the integration of VR and AR technologies in maritime and shipping. MarISOT (Maritime ISOT) consists of four VR simulators: command bridge, engine room, crane, and fire safety module. However, mentioned simulators do not consider the interaction of different parties during normal ship operations, as well as do not take into account the role of spatial awareness in the educational process. The ship design sector is gaining advantages through VR implementation. The cost of design communication can be reduced through the application of VR tools, providing enough realism, user experience optimization, and broad data compatibility [16]. The paper [17] is devoted to the application of AR technologies for the remote maintenance of autonomous ships and presents an outline of appropriate troubleshooting and machinery survey procedures from remote locations and training methods for the crew of autonomous ships of the future.

Extended reality (XR) covers various technologies that alter or enhance the reality we perceive. Some of these technologies are:

- Virtual reality (VR), which creates a fully immersive and simulated environment that replaces the real one.
- Augmented reality (AR), which adds digital elements or information to the real environment, usually through a smartphone camera or a wearable device.
- Mixed reality (MR), which combines VR and AR to create a hybrid environment where real and virtual objects can interact with each other.

These technologies offer several advantages over traditional training methods, such as:

- XR allows trainees to practice complex processes in a safe and controlled environment, reducing the risks associated with traditional training methods.
- XR provides trainees with a realistic simulation of ship operations, so they can develop the necessary skills and knowledge to perform their duties safely and effectively in real-world scenarios.
- XR offers the potential for more personalized and engaging learning experiences, by incorporating real-world data and scenarios into training programs.
- In XR spatial awareness is heightened due to the immersive experience of being physically present in a virtual environment, which can help the user develop better situational awareness skills. XR can also create a sense of presence and emotional involvement, that can increase motivation and engagement of the users.
- In certain applications XR eliminates the need for expensive equipment and facilities, leading to a significant cost reduction of the training process.

For instance, simulation of real mooring equipment in mooring operations training for the scale of a modern large tanker or container ship is practically impossible and bears high risks for the trainees. However, XR can overcome this limitation by creating a virtual environment that mimics the real conditions and challenges of mooring operations.

On the other hand, XR systems also pose some challenges, such as:

- When using a VR head-mounted device (HMD), the user may see and hear a simulated movement in the VR environment, but the body may not feel any corresponding motion, which may cause such symptoms as nausea, dizziness, headache, and fatigue.
- Motion sickness can affect the user's perception, performance, and learning outcomes in XR systems.

Therefore, it is important to design VR systems that can minimize motion sickness and maximize user comfort. Several works [18-20] have studied the possible contributors to VR sickness as well as sickness reduction methods. According to the mentioned studies, a visual-vestibular conflict depends on the type of content (moving or static), and studies comparing processed data show that content is a major contributing factor that influences VR sickness symptoms. In this way, it is important not only to provide high-quality simulation space but also to properly test and adjust the mechanics of user-XR interaction, e.g., speed of movement, rotation, brightness, etc.

In conclusion, extended reality technologies, specifically virtual reality, have the potential to greatly benefit training systems. However, like any other technology, it has its advantages and disadvantages. The aim of this research is to determine the appropriate application of advanced technologies in order to meet the required learning objectives and satisfy criteria such as:

- efficiency – the training shall result in reaching planned learning objectives.
- availability – the amount of individual access (repetitive if necessary) to all training content and tools for each student shall be maximized.
- cost – overall capital and operational expenses shall be as low as reasonably practicable.
- safety – the training environment must be as safe as reasonably practicable.
- comfort – the training environment shall be justifiably comfortable.

This paper will review a case study of "Maritime resource management" focusing on the training structure in order to enhance the availability and generic structure of the multi-station simulator, as well as techniques aimed at improving user comfort when using XR.

2. Case Study: Maritime Resource Management.

According to EMSA statistics for the period from 2014 to 2020, more than half of the accidents (58.4%) were related to the navigational nature, i.e., contact, grounding, stranding, capsizing, and collision involving multi-vessel operation. For this reason, the present study is mostly focused on the application of the technologies to navigational simulators. The most critical stages of the ship passage include navigation in busy traffic areas and constrained waters (narrow straits, rivers, canals, harbours). Mentioned areas are commonly associated with pilotage and towing services, which are mandatory for a vast majority of visiting vessels. About 55% of maritime accidents occur in inland waters, especially in port areas. Based on the analysis conducted during the investigations, it was concluded that during the same period, 89.5% of incidents were related to human erroneous actions. In terms of human factors, "safety recommendations" and "actions taken" were mainly addressed to the training, skills, and experience of all the parties involved (50.8%) [21].

The International Convention on Standards of Training, Certification, and Watchkeeping (STCW) for Seafarers sets the global requirements for the education and training of seafarers. According to the Manila Amendments 2010 requirement, officers must be aware of bridge resource management (BRM) principles. This requirement can be met by completing approved BRM training or simulator training and demonstrating competence in this area (STCW Code as amended, table A-11/1) [22]. STCW Convention also provides the use of simulators for the training of seafarers in Regulation I/12 "Use of simulators" and Section A-I/12 "Standards governing the use of simulators", B-I/12 "Guidance regarding the use of simulators of the STCW Code". Ship handling and Bridge Resource Management (BRM) training are crucial for developing the skills and competencies of bridge team members, including situational awareness, communication, decision-making, teamwork, and leadership. A conventional full-mission bridge simulator is commonly used to conduct BRM courses. However, one of the limitations of BRM simulation training is the lack of real interaction between all parties involved. Even when a pilot role is assigned, tug operation is often presented as a vector on an electronic chart display or handled automatically by the simulator. Mooring teams' operations are usually not considered at all in the majority of modern BRM training programs.

That's why a wider scope maritime resource management (MRM) training, which involves actual tug operators and, where appropriate, mooring team leaders may be a better alternative. Simulating the interaction between the vessel bridge, tugs and mooring teams could improve the training quality for deck officers, pilots, and tug captains. Additionally, simulating communication and coordination with tugboats can enhance the learning outcomes of bridge team members and pilots by improving their understanding of the role and limitations of tugs, as well as their own responsibilities and expectations. They can also practice dealing with emergency situations involving tugs, such as loss of power, towline failure, or collision, and develop resilience skills such as adaptability, flexibility, and creativity by coping with complex and dynamic situations that require collaboration with tugs.

Due to the nature of deck officers' duties (all levels from 3^{rd} officer to master), a lack of ship handling experience can be a significant challenge for the maritime industry. Deck officers rarely maneuver the ship in constrained waters, and practically when masters do so, they often simply follow rudder and engine orders from the pilot. Ship handling is a complex and demanding task that requires a high level of skill and expertise. Without adequate training and experience, deck officers may struggle to effectively navigate ships in challenging constrained conditions, increasing the risk of incidents.

To address this issue, it is essential to provide adequate training to improve ship handling skills through a combination of different approaches and methods such as desktop or web applications, conventional full-mission and virtual reality bridge simulators. In addition, it is important to take into account spatial awareness, which is a significant skill for maritime operations, as it enables bridge team members to maintain situational awareness, plan and execute manoeuvers, avoid collisions, and navigate safely. Spatial awareness can be developed and improved through training, especially with the use of simulators that can provide realistic and immersive scenarios. However, spatial awareness in VR and conventional full-mission bridge simulators are different in terms of the degree of realism and immersion they offer.

Nowadays, web-based e-learning is widely used for education and training, showing not only a high level of efficiency but also positive feedback from the students [23-26]. Therefore, it is important to emphasize, that to reach the full potential of ship handling and BRM skills via training the whole stack of available technologies should be used in the following or interchangeable modular order:

Stage 1. Theoretical training with the help of personalized web-based e-learning.

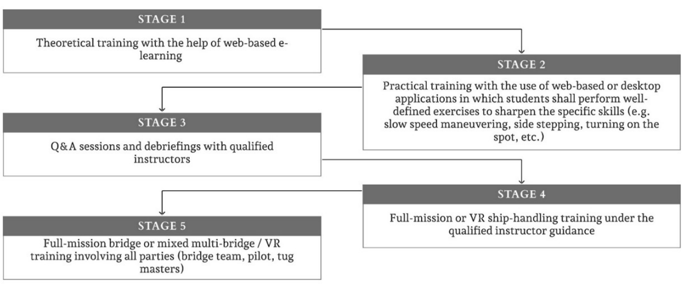
Stage 2. Practical training with the use of personalized web-based or desktop applications in which students shall perform well-defined exercises to sharpen specific skills (e.g. slow speed maneuvering, side stepping, turning on the spot, etc.).

Stage 3. Q&A sessions and debriefings with qualified instructors.

Stage 4. Full-mission or VR ship-handling training under qualified instructor guidance.

Stage 5. Full-mission bridge or mixed multi-bridge / VR training involving all parties (bridge team, pilot, tug masters).

Figure 1: Suggested scheme for ship handling and team management skills development.



Source: Authors.

Stage 1 objective is to set up the foundation for further learning and it might be beneficial to enable the students to learn at their own pace and to come back to certain materials throughout the time of the course or even after. That's where e-learning fits best.

Stage 2 is something that is currently missing in a modern-day ship handling training scheme. Its objective is to enable students to sharpen their practical skills at their own pace and take as much time as they need, which can be done using WebGL, RDP (remote desktop protocol), or similar technologies. Maneuvering ships of any size in real-time takes hours and practicing maneuvering takes days. Rarely do students have this opportunity in a conventional academic setting.

Subject matter expert (SME) advice and guidance is essential in **Stage 3** and must be available throughout the training.

The lack of spatial awareness and what mariners call "the feeling of ship inertia" can be compensated for by using a full-mission bridge, mixed or virtual reality (MR or VR) simulator in **Stage 4**. The important feature is that each student shall have an opportunity to practice individually, which in the case of a full-mission bridge simulator is not cost-effective. However, the use of smaller MR consoles or individual wireless VR headsets with joysticks is a feasible option due to much lower cost and space requirements.

Stage 5 suggests the whole team be present, where teams can utilize either combination of XR simulator stations or full-mission simulators. The latter is a rather demanding option with respect to cost and required space.

3. Practical Implementation in Software Development and Training .

The approach described above is being implemented by authors in TCCS NU "Odessa Maritime Academy" using Learnmarine [27] training programs related to ship handling and crane operations.

Stages 1 and 2 are implemented via LMS (learning management system) as a combination of e-learning and WebGL simulation technology. Students have access to the learning content through a whole period of training. During this period, students have to pass multi-choice tests and complete specially designed exercises on WebGL application using their personal devices (usually, a laptop).

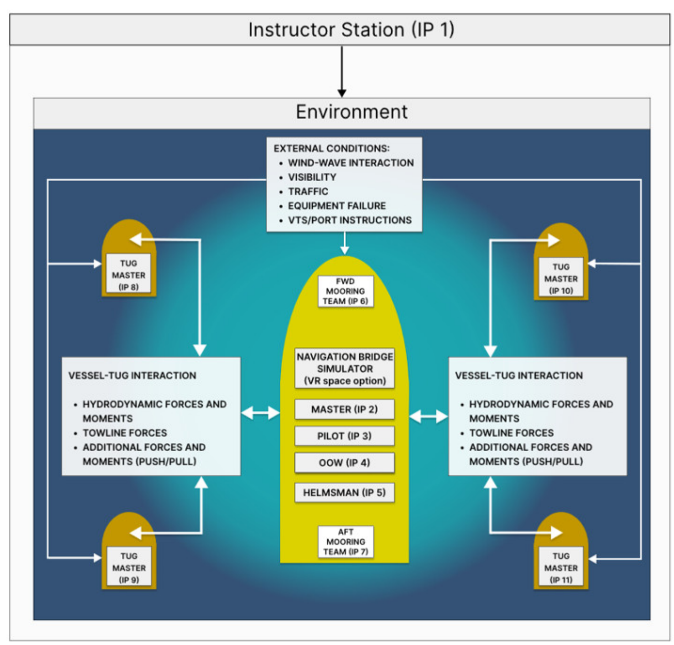
Stage 3 can be done either in a physical or virtual classroom using video conferencing software (e.g. Zoom, MS Teams, Google Meet).

Stages 4 and 5 require students' physical presence at the training facility and the corresponding hardware. Further, a multi-station simulator structure will be discussed, highlighting specific solutions and analysing students' feedback related to possible cases of VR sickness.

3.1. *Simulator System Structure.*

Multi-station ship handling simulator would have the same communication structure either for full-mission or extended reality case (Figure 2):

Figure 2: Multi-vessel operation simulator diagram.



Source: Authors.

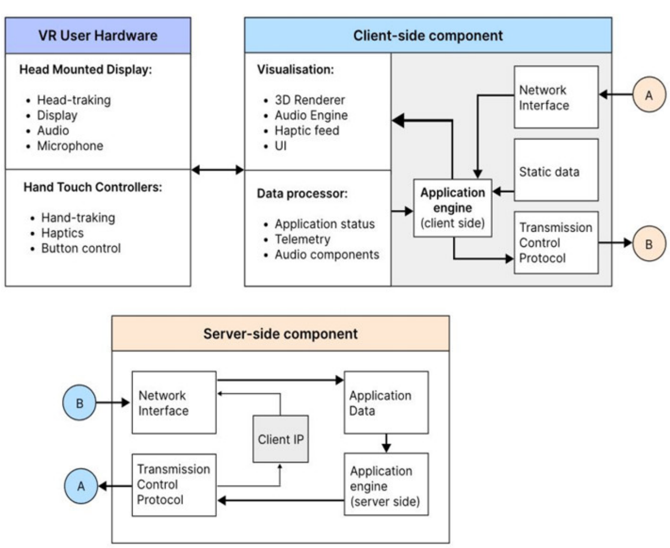
1. Instructor (IP-1) is the main client, assigned to start the exercise (create the environment) as well as to control external conditions, trainees' data, and activity records. In addition, instructor possesses access to server-side data;

2. Navigation bridge simulator is the space inside the environment, created by the instructor. Up to 4 users can connect to the bridge team. In this case, the vessel experience interaction with external conditions and the escorting or towing tugs;
3. Optionally, 2 individual stations can be connected representing forward and aft mooring stations' team leaders in the corresponding virtual spaces.
4. Tug vessel spaces are intended to include tug masters in the training process. In this example, up to 4 separate spaces can be created inside the environment. Tugs interact with the vessel, depending on the task (escort, push, pull or mixed). The interaction results in realistic multi-vessel behaviour, providing closer to real situation experience.

Suggested multi-vessel operation behaviour is based on the VR multi-player architecture (Figure 3).

The simulation process is provided by the application engine, which receives inputs from the user side and the server side. One of the conventional architectural approaches for a multi-ship simulation is to use a separate station for physics calculation. The main drawback of this approach is that if this station freezes or drops out from the network the whole simulation has to be restarted. The key difference between a suggested multi-ship simulator structure and existing alternatives is that each station's physics is calculated locally on a student's device and sent to the application engine, which provides better stability of the system in case one of the stations drops out from the simulation environment.

Figure 3: Scheme of VR multi-player architecture.



Source: Authors.

3.2. Considerations on ergonomics.

1. VR simulator posture (standing versus sitting) and motions.

There is no definitive answer to which posture is better for VR, as it may depend on the specific context and goals of the VR application. However, there are some general guidelines and recommendations that can be derived from the existing research, such as:

- Sitting may be more comfortable, safe, and accessible for users who have limited mobility, space, or time to use VR.
- Standing may be more immersive, engaging, and realistic for users who want to explore or interact with the VR environment in a natural way.

During the design process, both postures were used and tested. It is important to note that even when sitting user still can virtually move around the scene via so-called locomotion, in other words using joysticks to move, turn or teleport. It is important though to limit locomotion velocities in order to minimize the risk of motion sickness and use teleportation points where appropriate.

Although for applications that require a considerable quantity of movement and interaction with different mechanisms such as a mooring simulator (Figure 6) standing VR provides better immersive experience.

Seated VR experiences are less physically demanding and can reduce discomfort in the legs, feet, and back. Handling the ship doesn't require a lot of movement, in fact, most of the modern bridge systems are equipped with Bridge chairs. Therefore, for bridge team members either on the main vessel or on the tugs a seated position was chosen as preferable.

Figure 4: Sitting and standing variations of the ASD Tug simulator.

Source: Authors.

2. VR joysticks versus realistic manipulators

As can be seen from Figure 4 both types of controllers were used on the design stage for the ASD tug simulator. Extensive testing showed that for applications like mooring simulator or even large ship handling standard VR joysticks (e.g. Meta Quest 2) can be used to interact with the virtual environment whether it is a mooring winch component, ship's helm, or ship's engine. It is related to the relatively slow reactions of a large ship to changes in set rudder angle or engine telegraph position.

Operating a tug or a crane requires constant interaction with the controllers, which are ergonomically designed for specific

Figure 5: Mooring Simulator (Learnmarine).

Source: Authors.

manipulators. Developing a motoric memory for joysticks positions and specific buttons is important, as the operator's attention has to be constantly focused on the outside view. This could be either a suspended load or the actual disposition of the tug in relation to a towed vessel. However, this is usually hard to achieve by using VR joysticks. Trying to change the position of a virtual ASD manipulator using a joystick requires visual contact with the latter (Figure 4, right image). Therefore, the use of specific manipulators becomes critical to safety and a successful training process.

When simulator-specific manipulators are used other peripheral equipment can be interacted with using hand tracking, which is available in modern headsets (Meta Quest 2 and above).

3. Graphics and optimization.

The detailed analysis of graphics optimization techniques might be out of the scope of this research paper. However, there are some key points that are worth mentioning.

The smooth application graphics along with motion speed and posture is one of the core components of a comfortable VR experience and usually depends both on target platform productivity and application graphics optimization,

During the development, it is recommended to use the guidelines from the chosen VR headset manufacturer, that in this case was Meta Quest 2 [28].

This VR headset model supports independent operation (PC is not required). However, for most complicated simulations the design team found the use of "Meta Quest Link" (using PC hardware for simulation, while the headset is connected either via Wi-Fi or wired link) more beneficial. According to [28] interactive applications must target a minimum of 72 frames per second, which is hard to achieve on a standalone headset without very rigorous optimization (textures size minimization, limited use of lighting and shadows, occlusion culling, reduction of total 3D models polygons etc.).

On the other hand, a modern gaming PC (e.g. CPU: Intel Core i5-4590, AMD Ryzen 5 1500X, or Intel Core i7 11700F1-2345; GPU: NVIDIA GeForce GTX 1060, AMD Radeon RX 480, NVIDIA GeForce RTX 3080, or NVIDIA GeForce GTX 108012345; RAM: 8+ GB) can easily support quite demanding VR applications.

The Meta Quest Link can be either wireless (5 GHz band Wi-Fi) or wired (USB 3 link cable). The wireless connection provides better freedom of movement whereas cable connection provides more stable and faster simulation. For this reason, the cable connection is the preferred option for seated simulators such as ASD Tug or crane simulator.

4. Testing of equipment.

The development of a multi-station simulator commenced in 2020 as a collaborative project between TCCS NU "Odessa Maritime Academy" and Learnmarine and is currently ongoing. Presented below are the results of the approbation and testing of one of the currently available components – ASD tug simulator.

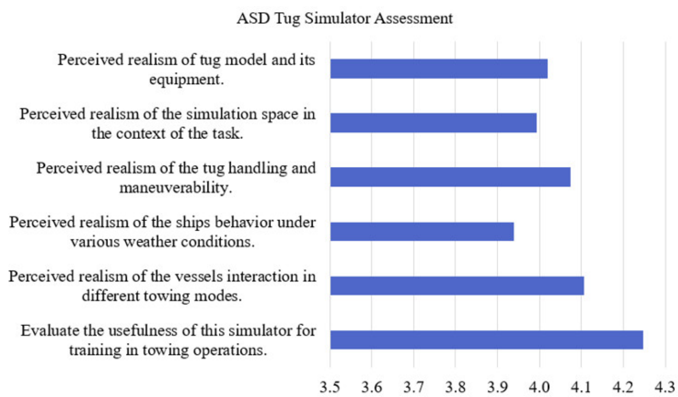
The functionality of the Learnmarine ASD-Tug handling simulator is based on the mathematical model of ship interaction described in [29-31], and allows performing the training in tug operations and includes the following features:

- control of the ASD tug movement both via the mouse, extended reality (XR) and azimuthal thruster controllers;
- manoeuvring modes: tug alone, escort, towing, as well as operation while mooring/unmooring and departure from the berth;
- control of meteorological conditions, namely the speed and direction of wind and current, the height and direction of waves, as well as visibility, time of day and weather conditions;
- selection of the securing points of towing ropes and control of their tension;
- a realistic scenario and simulation environment supported by mathematical modelling of the ship's dynamics, taking into account the stability features of azimuth tugs.

The adequacy of the Learnmarine ASD Tug handling simulator was evaluated by local subject matter experts (SMEs), including tug masters from the port of Odesa, Ukraine. The perceived realism of vessel interactions in different towing modes was evaluated as 4.11 out of 5 points, based on a questionnaire completed after using the simulator. The conditions leading to dangerous states in relation to tug manoeuvrability and stability were confirmed to be close to the real sea experience of the invited SMEs. Additionally, the SMEs noted that the simulator's main advantage is the ability to gain necessary skills in a realistic virtual environment without being exposed to dangerous situations. A summary of the simulator assessment is shown in the Figure 6.

In 2021 – 2022, seafarers participating in a refresher and updating training course at the Odesa Maritime Training Centre were invited to evaluate the quality and realism of the VR simulators. Of the general student population, 110 volunteers responded to the invitation. Most participants had considerable sea experience, with an average of 21.7 years in total and 9.5 years in rank. The feedback from these participants provided

Figure 6: Results of ASD-Tug handling simulator assessment by SMEs.

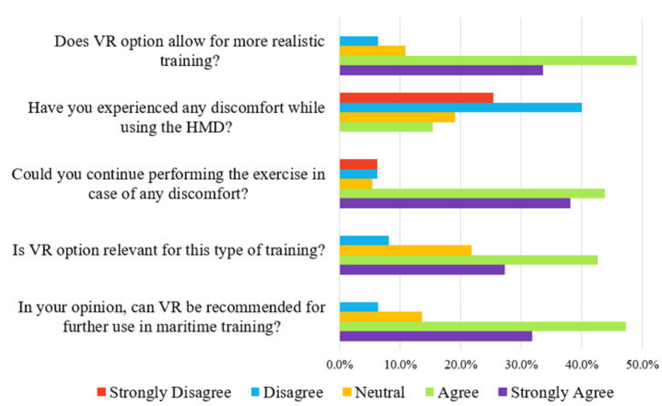


Source: Authors.

valuable insights into the strengths and weaknesses of the simulator, as well as its response to the virtual reality environment.

The generalized results of a questionnaire completed by each participant are presented in the Figure 7. As can be noticed from the survey results, over 80% agreed that virtual reality provides a more realistic learning experience. Seventy per cent responded positively to the question about the relevance of this type of training in the context of the maritime sector. About 79% would recommend using virtual reality in maritime education.

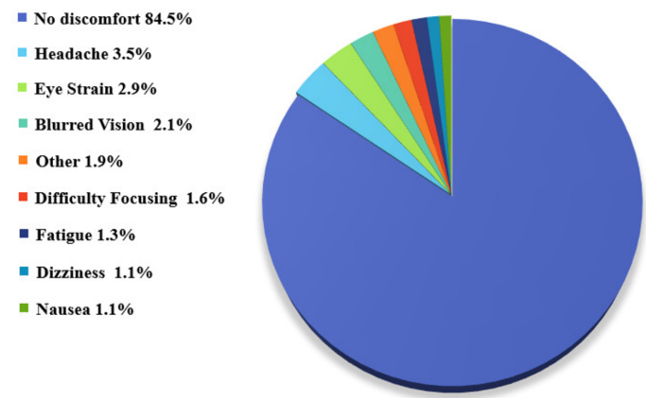
Figure 7: Questionnaire results on VR training experience.



Source: Authors.

Out of the total number of 110 volunteers, approximately 17 individuals experienced discomfort during the exercise, with 2 finding it difficult to continue. These volunteers were asked to describe the type of discomfort they experienced (Figure 8). It should be noted that the list of symptoms reported is consistent with the most common symptoms identified in relevant studies [32-34].

Figure 8: Types of discomfort (symptoms) experienced during VR use.



Source: Authors.

Conclusions.

The present study emphasizes the transformative potential of modern simulation technologies, particularly extended reality (XR), in enhancing maritime education and training (MET). The maritime industry's evolving demands for skilled seafarers, coupled with the challenges posed by conventional training methods, underscore the need for innovative solutions.

The study demonstrates the benefits of XR applications, such as virtual reality (VR) and augmented reality (AR), as well as web-based platforms, in creating immersive and safe training environments. These technologies offer unique advantages, including realistic simulations, personalized learning experiences, heightened spatial awareness, and enhanced engagement.

The proposed training framework outlines a multi-stage approach, spanning from theoretical e-learning to full-mission XR simulations. Practical implementations, exemplified by the Learnmarine ASD Tug handling simulator, showcase the effectiveness of XR in refining ship handling skills and enhancing maritime resource management.

While acknowledging the potential for motion sickness and other challenges associated with XR, the research underscores the importance of optimizing graphics, considering ergonomics, and addressing user comfort.

By harnessing the strengths of XR, the maritime industry can equip seafarers with essential skills, foster safety, and meet the demands of a rapidly evolving field. As technology continues to shape the maritime landscape, integrating XR into MET practices holds promise for cultivating proficient and resilient maritime professionals.

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