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EVALUATION OF SHIP SIMULATOR EFFECTIVENESS AND SUITABILITY BY MARITIME INSTRUCTORS

Abstract. Technology and the technological devices developed with it have become an indispensable part of our daily lives. Simulator technologies have been widely used in maritime education for many years, allowing maritime students to develop their maritime skills without the need for real ship experience. In this way, they can experience scenarios that cannot be experienced in real life because of safety, economic, and ethical constraints. This study seeks to determine the effectiveness and acceptability of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imaging, Liquid Cargo Handling, Electronic Navigation Devices simulators used in maritime training from the perspective of maritime instructors. In addition, it is aimed to reveal which simulator is the most accepted simulator according to the determined criteria. The study investigates the effects of the design and functionality of simulators on the training process while evaluating the effectiveness of simulators to improve the quality of maritime education and to provide cost-effective solutions that meet sectoral needs. The research data were collected using a questionnaire technique, and the importance levels of the criteria were calculated using the AHP method. This study compared the alternatives using the TOPSIS and PROMETHEE methods. In this study, it was determined that the most important criterion was ‘‘closeness to reality’’ and the least important criterion was ‘‘design esthetics’’, and in the ranking of simulators that met the criteria determined in both methods, the ECDIS simulator ranked first. In contrast, the ARPA Radar simulator ranked second. It can be seen that the rankings of the Ship Control, GMDSS, and Liquid Cargo Handling simulators are the same for both methods. This study contributes to the maritime literature as it reveals the importance levels of the criteria that determine the effectiveness of simulators used in the training of deck-class seafarers and identifies the most suitable simulators according to these criteria. The novelty of this study lies in its contribution to the limited research on the evaluation of simulator effectiveness by maritime instructors within the maritime sector. While inadequately designed simulators negatively affect the learning process and hinder the development of professional skills, effective and accepted simulators play a critical role in increasing the quality of maritime education and providing cost-effective solutions that meet the needs of the sector.

Keywords: Maritime Education; Ship Simulator; AHP; TOPSIS; PROMETHEE.

1. INTRODUCTION

The problem statement. Maritime education has undergone a major transformation with technological developments and simulators have gained an important place in this education process. Simulators, which are required by international conventions to be used in maritime education, play a critical role in improving the quality of education and providing solutions in line with the needs of the sector while enabling students to improve their professional skills. However, the opinions of maritime educators on the realism, functionality and effectiveness of different types of maritime simulators are not fully known.

Although there are several studies in the existing literature on improving the quality of maritime education, there is a lack of a comprehensive comparative analysis focusing on maritime educators' evaluations of the effectiveness of simulators. In this context, this study aims to investigate the criteria by which the effectiveness of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imaging, Liquid Cargo Handling and Electronic Navigation Devices simulators are evaluated. Which simulator is considered to be the most accepted and effective simulator by maritime educators?

Technology and its systems, equipment, and devices have become an indispensable part of our lives. In addition, technological advances have facilitated our lives and increased the necessity of specialization in business lines that serve various branches [1]. It is important for the workforce operating in the maritime sector to have the competencies to participate at the international level, communicate effectively between different disciplines, adapt quickly to technological changes, make effective decisions in sudden situations, and in areas such as cargo operations, navigation, engine room, and deck in the maritime sector may cause high costs and loss of life, it is vital that training is conducted in a realistic and safe manner. For this reason, it is necessary to establish high-quality training infrastructure according to international standards for the training of seafarers. Simulators, which are used in almost every field and enable the identification of possible problems [2], are also used in maritime education worldwide to train qualified and responsible officers, captains, and engineers for ships. These simulators operate safely and effectively. Because mistakes that may occur present virtual reality and real environments to users with minimum risk [3] and effectively provide realistic and qualified maritime training.

Face-to-face trainings offer the opportunity to acquire general and broad knowledge and the competencies acquired in this way cannot be easily acquired in any other way [4]. Establishing good communication between instructors and students and providing an interactive learning environment facilitates effective and permanent student learning [5]. Using simulators in maritime education allows students to develop maritime skills without the need for real ship experience, and simulator-based education makes it possible to create scenarios that are not possible in real life because of safety, economic, and ethical constraints. Three-dimensional (3D) visualization reduces the gap between simulation and real life and promotes effective learning. Simulator training increases students' ability to assess hazardous situations and provides an environment to support more collaborative, case-based learning and critical thinking than traditional classroom-based exercises. Simulator technologies have been widely used in maritime education for many years, and the Standards for the Training, Certification, and Watchkeeping of Seafarers (STCW) are actively supported by the International Maritime Organization (IMO) [6]. In addition, the IMO has established a maritime community, which includes maritime organizations and qualified institutions such as the International Marine Simulator Forum (IMSF), the International Maritime Instructors Association (IMLA), and Det Norske Veritas (DNV), which have come together to develop technical standards for simulators [7].

STCW represents the standards, criteria, and certification required for international qualifications in seafarer training. These standards, established to adapt to the developing technology and global maritime requirements, define seafarers' knowledge, skills, and competencies at the international level and contribute to the sustainable maritime sector. STCW is the most important basic reference source in the field of maritime training, and all maritime training and seafarer certifications must comply with this convention [8]. For high-level training, institutions should provide practical and theoretical training that fulfills the requirements of the STCW convention [9]. Internationally recognized simulators with a certificate of conformity in maritime training according to STCW and approved by the administration are registered in the GIBS (Ship People Information System) module for relevant training. Unapproved simulators are not accepted when they are registered in the module [10]. The simulators that need to be approved are bridge simulators, engine room simulators, oil, chemical, and liquefied gas tanker cargo handling simulators, ECDIS (Electronic Chart Display Information System) simulator, GMDSS (Global Maritime Distress Safety System) simulators, and ARPA (Automatic Radar Plotting Aid) Radar simulator.

A bridge simulator is a piece of laboratory hardware and software that simulates the behavior of a ship from a point on its bridge, usually consisting of a model bridge that resembles a real bridge. Consoles, displays, and visualization screens project a 3D view of the outside world, on which environmental elements such as ships, islands, and harbors can be displayed [11].

The engine room simulator is divided into a full-function simulator and a PC-based simulator. It consists of the engine room, engine control room, and training room for the training of ship personnel. The engine room section has interactive simulation panels that simulate all the machinery and systems in the ship engine room. The engine control room contains the engine remote control console, various automated systems (AutoChief, PowerChief), power distribution panels, and a workstation. In contrast, the trainer room allows control of all systems, creates faults, and organizes scenarios [12].

A liquid cargo handling simulator is a training tool used in crude oil carriers' loading and unloading processes. In this simulator, the deck officer controls a number of systems, such as the main cargo, cargo stripping, ballast, and crude oil washing systems. In addition, monitoring important ship parameters is among the functions of the simulator [13].

The ECDIS simulator is a real-time decision support system for the navigational safety of ships, and systems complying with the standards set by IMO in 1995 allowed the use of ECDIS consoles instead of paper charts. The ECDIS displays electronic charts conforming to IMO and IHO (International Hydrographic Organization) standards and the readings of navigational aids on a screen. The system processes this information to provide navigational decision support information and maintains the necessary records [14]. The simulator simulates different scenarios using navigation software and ship control systems.

The GMDSS simulator's key goal is to communicate by informing and warning coastal centers and nearby ships of danger and ensuring sea safety [1]. In extraordinary situations, this system aims to enable the unit in danger to quickly notify the emergency situation to the search and rescue units and provide the necessary assistance to the unit in danger in a fast and systematic manner with terrestrial and satellite-based devices [15] connected to the navigation area (A1-A4) on board ships [16]. GMDSS simulators provide the opportunity to perform radio communication, radio use, maritime search and rescue operations, and other GMDSS communication procedures by simulating different emergency scenarios.

The ARPA radar simulator can calculate the tracked object's course, speed, Point of Proximity (CPA), Time to Closest Approach (TCPA), and bow crossing distance (BCR) between two ships if no course or speed adjustment is made. It is a system that can calculate how close a target will pass to the bow of a ship so that there is no risk of collision with another ship or land mass [17]. This simulator allows users to improve their ability to interpret radar displays, reduce the risk of collision with other vessels, increase the safety of navigation at sea, and improve their ability to react accurately and effectively in emergencies.

Analysis of recent studies and publications. Looking at the studies on technology and simulators used in maritime education, Ref. [18] conducted a systematic literature review between 2005 and 2021, examined how accurately maritime simulators represent real ships and their environments, revealed that there is no consensus on whether maritime simulator and accuracy levels in simulators increase training results and emphasized the need for further research and standardization in this field. Ref. [19] discussed the use of object-based physical modeling technology for marine technology simulators of TRANSAS Technologies and its impact on the formation of real-time mathematical models in modern liquid cargo handling simulators and created meaningful clusters among countries and cities by investigating simulator facilities worldwide and identified leading countries and cities that can be a reference in maritime education. Ref. [20] examined Maritime Autonomous Surface Ship (MASS) technology, reviewed the changes in education and training in the sector, and updated the qualifications. They emphasized the necessity of the existence of smart mariners with coordinated management capabilities in areas such as artificial intelligence, cybersecurity, and the digital system revolution. In the study examining the potential benefits, disadvantages, and limitations of Virtual Reality (VR), Augmented Reality (AR), and mixed reality (MR) applications for maritime training and operations, it was stated that these applications offer new possibilities to maritime training and operations, providing more affordable, flexible and portable alternatives compared to industry standards [6]. In his study, Ref. [21] conducted a bibliometric analysis to understand the current situation in the literature by examining advanced teaching methods in maritime education and found that there are gaps in the literature on the subject. Ref. [22], in their study, emphasized that in the selection of simulation, it is preferable to provide fast and high-quality service with state-of-the-art hardware and software systems close to reality, but stated that it is important to increase the minimum requirements that simulators should have in accordance with the STCW Convention instead of improving the simulations in schools in seafarer training. In their study, Ref. [23] stated that the use of ship simulations has a positive effect on students' professional competencies and contributes to business life when demographic factors such as age and educational status are taken into consideration, is effective in gaining knowledge and skills, and increases students' self-confidence by encouraging active use of knowledge. Ref. [12] examined in detail how Ship Engine Room Simulators (SES) are integrated with other applied training methods in Marine Engineering education, namely training ships and offshore training on merchant ships, and at which stages they are used. The possible effects of these approaches on improving the quality of education are discussed with examples. In a study that discusses the importance and current status of simulator-based education in maritime education, marine simulators were examined, technological and pedagogical advances in maritime education were examined, how simulators could be used more effectively in maritime education, and what could be done to improve educational practices [24]. In Ref. [25], a hybrid MCDM approach was developed to evaluate simulators used in maritime training. Thirteen sub-criteria based on technical, educational and organizational criteria were analyzed by Bayesian Best-Worst Method and PROMETHEE methods. The results of the study showed that regulatory compliance is the most important criterion and cost is the least important criterion; full-mission simulators are generally the most preferred type. As is understood from studies in the literature, technological developments and innovations are of great importance in the maritime industry, and it is emphasized that the use of simulation technologies in this field should be increased, developed, standardized, and disseminated [19], [22]. In addition, making simulators more realistic and effective is seen as an important step to increase students' professional competencies and meet the demands of the maritime industry [20], [24]. Emphasizing the significance of the role of novel technologies and simulations in maritime education, studies have been conducted on the possible benefits of integrating new technologies such as simulations, artificial intelligence, virtual reality, and augmented reality into maritime education [6], [12], [21].

The research goal. This study aims to evaluate the effectiveness of different simulators from the perspective of maritime educators and to identify the most accepted simulator in maritime education. The study investigates the effects of the design and functionality of simulators on the training process while evaluating the effectiveness of simulators to improve the quality of maritime education and to provide cost-effective solutions that meet sectoral needs.

The literature has investigated the ability of simulators used in maritime training to accurately represent real ships and their environments, their impact on training outcomes and the need for standardization in this area. In addition, studies have examined the integration of new technologies and simulators into training, the impact of demographic factors on training and advanced evaluation methods for simulator selection. In this context, the effectiveness and acceptability of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imagery, Liquid Cargo Handling and electronic navigation device simulators, which are mandatory for deck officer training, were determined in this study. According to which criteria the users accept simulators in deck class officer training and which simulator is adopted more according to these criteria were determined and did not contribute to the maritime literature. In addition, the study contributes to the strategic planning efforts in the maritime sector and development programs for the application of technology in education by filling the knowledge gaps regarding the application of simulators in maritime education.

2. RESEARCH METHODS

The 9 criteria selected to determine the effectiveness of ship simulators in the research were determined by making use of studies on ease of use, closeness to reality, usefulness in the evaluation and decision-making process, success in the learning process, effectiveness in teamwork, success for the relevant application, habit, design esthetics, enjoyment [18], [26].

The research data were obtained from maritime educators between February 01 and March 5, 2024, using the questionnaire technique. The Analytical Hierarchy Process (AHP), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and PROMETHEE (Preference Ranking Enrichment Evaluation Method - Preference Ranking Organization Method for Enrichment Evaluation) methods were applied to analyze the data.

Multi-criteria decision-making (MCDM) methods involve ranking a variety of concrete alternatives based on a number of conflicting criteria and include theories and methodologies developed to solve complicated problems in management, business, engineering, science, and many other human activities. Studies in this field provide decision-makers with analytical and mathematical methods to make effective decisions in multi-criteria environments [27]. Various MCDM methods have recently been developed to help identify the best alternatives, and these methods have also emerged due to practitioners' efforts to produce more advanced decision-making strategies using advances in mathematical optimization and computer technology [28].

Ref. [29] examined the applicability of the most suitable marina option by determining the preference criteria of yacht owners. The weight input values obtained using the AHP method were evaluated in MCDM methods, such as TOPSIS and PROMETHEE. By comparing the preferences of yacht owners and the results obtained by these methods, the contributions of the methods to the decision-making process were evaluated. The results show that AHP, TOPSIS, and PROMETHEE are effective decision-support tools in the marina selection process. The criteria prioritized by a company in the cargo selection process were determined by experts and the importance levels of these criteria were analyzed via the AHP method [30]. In line with the determined importance levels of the criteria, it was determined which cargo companies the company cooperates with. Company employees rated the alternatives based on the determined criteria; a decision matrix was formed. Finally, the solution results were compared using the TOPSIS and PROMETHEE methods over this matrix. Ref. [31] addressed the selection of personnel to operate machines with special features in textile factories. First, pre-selection was performed using the weighted scoring method. Then, the main criteria for the factory were identified through the AHP method. Finally, the TOPSIS and PROMETHEE methods were applied to ensure correct candidate selection. This study has made significant contributions to achieving effective results in candidate selection by integrating the weighted scoring method, the AHP method, and the MCDM methods, as well as real business processes.

2.1. AHP Method

AHP typically uses a pairwise comparison scale to reveal the significance of each criterion (Table 1). This process attempts to determine the degree of importance of each criterion relative to the other by comparing different criteria.

Table 1

AHP criteria assessment scale [32].

Degrees	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values in Reconciliation

The AHP follows five main steps, which are summarized in Table 2. The first three steps focus on the calculation of weights, while the last two steps check the cross-consistencies in pairwise comparisons; therefore, AHP can be defined as an effective quantitative method for converting judgments into criteria weights on a ratio scale [33].

Table 2

AHP process steps [34], [35]

Queue	Formula	Description
1	$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1j} \\ 1/a_{12} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1j} & 1/a_{2j} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1j} \\ b_{21} & b_{22} & \cdots & b_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ b_{i1} & b_{i2} & \cdots & b_{ij} \end{bmatrix}$	Based on expert opinions, a matrix B=[bij] is created for pairwise comparisons (evaluations on a 17-point scale, 1/9, 1/8,..., 8, 9).
2	$c_{ij} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}}$	Matrix B is normalized by the total value of each column to obtain matrix [cij].
3	$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n}$	The row sums of the C matrix are divided by the number of criteria (n) to calculate column matrix W, which is the weight of each criterion.
4	$\lambda = \frac{\sum \frac{d_i}{w_i}}{n}$	The average ratio of the values of the D matrix to its weight (λ) is calculated. Matrix D is formed by multiplying matrix B obtained by pairwise comparisons with matrix W.
5	CR=$\frac{(\lambda-n)/(n-1)}{RI}$	To determine the consistency of pairwise comparisons in matrix B, CR (Consistency Ratio) is calculated. The CR value is evaluated according to Saaty's consistency criterion, which should be less than 0.10. n : 3 4 5 5 6 7 ... RI: 0.58 0.90 1.12 1.24 1.32 ...

2.2. TOPSIS Method

The TOPSIS method was first proposed by [36] and is an important technique in the field of MCDM. This method is applied to the MCDM process by ranking alternatives using a set of criteria and determining the most appropriate alternative that should be selected. TOPSIS places alternatives in a ranking order from best to worst. The best alternative is either the nearest to the positive ideal solution or the farthest from the negative ideal solution [37]. The stages of Table 3 show the TOPSIS method in detail.

Table 3

The TOPSIS process steps [34], [36]

Queue	Process
1	A decision matrix (A) is prepared using with cell elements aij.
2	$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{n} a_{ij}^2}}$ The elements in matrix A are standardized.
3	$v_{ij} = w_i . r_{ij}$ The weighted standardized decision matrix was created using the following formula. Here, wi are the weights of each criterion, summing to 1.
4	Based on the criteria, the most desirable ideal (A') and the most undesirable negative ideal (A') solutions are identified. Here, J represents utility and J' represents cost. $A^* = \{(max_i v_{ij} \| j \in J), (min_i v_{ij} \| j \in J')\}$ $A^- = \{(min_i v_{ij} \| j \in J), (max_i v_{ij} \| j \in J')\}$
5	For each alternative, deviations from the ideal and non-ideal solution sets were calculated. $D_j^* = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_i^*)}\, ; D_j^- = \sqrt{\sum_{i=1}^{n}(v_{ij} - v_i^-)^2}$
6	The relative distances of each decision maker's degree of uncertainty (DUDM) to the ideal solution are calculated. $C_j^* = D_j^- / (D_j^* - D_j^-)$
7	According to the relative distances to the ideal solution, the preference order is from the largest number to the smallest number.

2.3. PROMETHEE Method

PROMETHEE is an MCDA method proposed by Ref. [38] and later improved by [39]. PROMETHEE is a superior method to rank and choose a set of alternative actions that often have conflicting criteria. Compared to other multi-criteria analysis methods, it is a relatively simple ranking method [40]. For this reason, the number of practitioners using the PROMETHEE method to solve practical multicriteria decision problems and scholars interested in the sensitivity aspects of this method are increasing annually [27]. Table 4 presents the steps of the PROMETHEE analysis.

Table 4

PROMETHEE process steps [38], [41], [42]

Queue	Process	Description
1	$\begin{bmatrix} a_{11} & a_{12} & L & a_{1j} \\ a_{21} & a_{22} & L & a_{2j} \\ M & M & O & M \\ a_{i1} & a_{i2} & L & a_{ij} \end{bmatrix} W = [w_1 \quad w_2 \quad L \quad w_i]$	The cell elements are organized as aij when creating decision matrix (A) and criteria weight matrix (W).

2	Usual: 0 for d≤0, 1 for d>0; Type U: 0 for d≤q, 1 for d>q; Type V: 0 for d≤0, d/p for 0<d≤p, 1 for d>q; Leveled: 0 for d≤q, 1/2 for q<d≤p, 1 for d>q; Linear: 0 for d≤q, (d-q)/(p-q) for q<d≤p, 1 for d>q; Gaussian: 0 for d≤0, 1-EXP(-d2/2s2)) for d>0.	In the decision-making process, preference functions suitable for each criterion are determined. For these functions, the indifference value (q, the large critical value), the definite preference threshold (p, the small critical value) and the observation/difference (d) values between these two values are determined over the DUDM values associated with certain criteria. In total, 6 different function types were considered.
3	$P(a,b)=\begin{cases} 0, f(a)\leq \text{f(b)} \\ p(f(a)-f(b)), f(a)>f(b) \end{cases}$	Values (Pj(a,b)) are calculated for pairwise comparisons between DUDM's (e.g. a and b). These values indicate how much a is preferred over b according to criterion j.
4	$\pi(a,b)=\frac{\sum_{i=1} w_j P_j(a,b)}{\sum_{i=1} w_j}$	Using the pairwise comparison scores, preference indices are calculated for each DUDM as one minus the DUDM.
5	$\Phi^{+}(a)=\frac{1}{n-1}\sum\pi(a,x)'$ $\Phi^{-}(a)=\frac{1}{n-1}\sum\pi(x,a)$	Preference indices are calculated for each DUDM. These indices were averaged horizontally and vertically to obtain positive Phi and negative Phi values.
6	For partial supremacy,; $\Phi C^{+}(a)>\Phi^{+}(b)\wedge\Phi^{-}(a)\leq\Phi^{-}(b);\vee\Phi^{+}(a)=\Phi^{+}(b)\wedge\Phi^{-}(a)<\Phi^{-}(b)$ For full prioritization,; $\Phi(a)=\Phi^{+}(a)-\Phi^{-}(a)$	The PROMETHEE 1 method allows partial ranking by comparing these Φ values. The PROMETHEE 2 method determines the net preference order by ranking Φ values from smallest to largest.

3. THE RESULTS AND DISCUSSION

The data collection process was carried out between February and April 2024, and data were obtained from 15 maritime educators who voluntarily participated in the research among the lecturers of the universities providing maritime education in Turkey via an e-mail survey technique. Table 5 presents the demographic characteristics of the participant experts. Although 13% of the participants were women, 87% were men. Furthermore, 69% of the participants were between the ages of 30 and 40, and the highest participation was at the age of 44 with 31%. In addition, 27% of the participants stated that they had worked at sea for 6-10 years, while 13% stated that they had worked for 16-20 years. Those with postgraduate education comprised 87% of the participants, while 13% were undergraduates.

Table 5

Demographic information about the participants.

Variable	Groups	Frequencies	Percentage (%)
Gender	Female	2	13
	Male	13	87
Age	30	1	8
	31	1	8
	32	1	8
	33	2	15
	35	1	8
	36	1	8

	39	1	8
	43	1	8
	44	4	31
	46	1	8
	51	1	8
Education Status	Undergraduate	2	13
	Graduate	13	87
Working Time at Sea	1-5 years	3	20
	6-10 years	4	27
	11-15 years	3	20
	16-20 years	2	13
	20 years or more	3	20
Mission	Distant First Officer, Seafarer Trainer	3	20
	Distant duty officer, seafarer trainer	3	20
	Long Distance Captain-Seafarer Trainer	9	53

3.1. AHP Method

In the research, the comparisons of the criteria selected to determine the effectiveness of ship simulators 'ease of use (A), closeness to reality (B), usefulness to the evaluation and decision-making process (C), success in the effect on the learning process (D), effectiveness in teamwork (E), success for the relevant application (F), habit (G), design esthetics (H), enjoyment (I)' were performed via the '1-9 scale' proposed by Saaty (1977), which is presented in Table 1, taking into account the opinions of seafarer educators who are ship people. While evaluating the criteria, comparisons were made and the different opinions were brought together with the geometric mean. Table 6 shows the obtained pairwise comparison matrix.

Table 6

Pairwise comparison matrix

CRITERIA	A	B	C	D	E	F	G	H	I
A	1,00	0,36	0,79	0,74	0,93	1,01	4,58	4,63	1,51
B	2,81	1,00	0,84	1,78	1,60	1,98	6,88	7,65	2,70
C	1,26	1,18	1,00	0,92	2,04	1,11	6,61	7,36	2,40
D	1,36	0,56	1,09	1,00	3,80	1,96	3,16	7,40	1,34
E	1,07	0,63	0,49	0,26	1,00	0,78	3,23	3,40	1,81
F	0,99	0,51	0,90	0,51	1,27	1,00	3,18	3,44	3,11
G	0,22	0,15	0,15	0,32	0,31	0,31	1,00	1,90	0,56
H	0,22	0,13	0,14	0,14	0,29	0,29	0,53	1,00	0,41
I	0,66	0,37	0,42	0,75	0,55	0,32	1,80	2,42	1,00
TOTAL	9,58	4,88	5,82	6,40	11,80	8,76	30,96	39,20	14,83

The [cij] matrix in Table 7 (normalized decision matrix) was formed by normalizing the decision matrix in Table 6 according to the total value of the column containing each criterion.

Table 7

Normalized decision matrix

Criteria	A	B	C	D	E	F	G	H	I
A	0,104	0,073	0,136	0,115	0,079	0,115	0,148	0,118	0,102

B	0,293	0,205	0,145	0,277	0,135	0,226	0,222	0,195	0,182
C	0,132	0,243	0,172	0,143	0,172	0,126	0,214	0,188	0,162
D	0,142	0,115	0,187	0,156	0,322	0,223	0,102	0,189	0,090
E	0,112	0,128	0,084	0,041	0,085	0,090	0,104	0,087	0,122
F	0,103	0,104	0,155	0,080	0,108	0,114	0,103	0,088	0,209
G	0,023	0,030	0,026	0,049	0,026	0,036	0,032	0,049	0,038
H	0,023	0,027	0,023	0,021	0,025	0,033	0,017	0,026	0,028
I	0,069	0,076	0,072	0,116	0,047	0,037	0,058	0,062	0,067

The criteria weights were calculated using the normalized decision matrix in Table 7. The weights are denoted by the symbol W and are included in Table 8.

Table 8

Normalized decision matrix and criteria weights

Criteria	A	B	C	D	E	F	C	H	I	W
A	0,104	0,073	0,136	0,115	0,079	0,115	0,148	0,118	0,102	0,110
B	0,293	0,205	0,145	0,277	0,135	0,226	0,222	0,195	0,182	0,209
C	0,132	0,243	0,172	0,143	0,172	0,126	0,214	0,188	0,162	0,172
D	0,142	0,115	0,187	0,156	0,322	0,223	0,102	0,189	0,090	0,170
E	0,112	0,128	0,084	0,041	0,085	0,090	0,104	0,087	0,122	0,095
F	0,103	0,104	0,155	0,080	0,108	0,114	0,103	0,088	0,209	0,118
G	0,023	0,030	0,026	0,049	0,026	0,036	0,032	0,049	0,038	0,034
H	0,023	0,027	0,023	0,021	0,025	0,033	0,017	0,026	0,028	0,025
I	0,069	0,076	0,072	0,116	0,047	0,037	0,058	0,062	0,067	0,067

Using the Excel program, λmax, the largest eigenvalue of the pairwise comparison matrix, and the consistency index (CI) and consistency index (CR) were calculated and presented in Table 9.

Table 9

λmax, CI, and CR values.

λmax,	9,33
CI	0,04
CR	0,03

Because the consistency ratio is less than 0.10, we conclude that the evaluations of the decision-makers are consistent.

The criteria weights shown in Table 8, which were determined according to the AHP results, were used for the TOPSIS and PROMETHEE methods in the following stages of the problem solution. The criterion that had the highest weight is " (0,209) closeness to reality" and the ranking of the other criteria is as follows; "(0,172) usefulness to the evaluation and decision-making process", "(0,170) success in its effect on the learning process", "(0,118) success for the relevant application", "(0,110) ease of use", "(0,095) effectiveness in teamwork, "(0,067) enjoyment", "(0,034) habit" and finally "(0,025) design esthetics".

3.2. TOPSIS Implementation

The decision matrix based on the data obtained from the maritime educators for the TOPSIS application is presented in Table 10.

Table 10

Decision matrix

Criteria	A	B	C	D	E	F	G	H	I
ARPA Radar	8,417	8,865	8,893	9,181	7,192	8,622	8,130	6,929	7,291
ECDIS	8,020	8,940	9,173	9,329	8,127	8,986	7,510	6,770	7,577
GMDSS	5,335	7,361	6,494	5,820	5,914	7,222	5,175	4,213	5,890
Ship Control	8,960	6,238	8,201	8,587	8,712	6,585	7,036	7,018	8,369
Environmental Display	8,332	7,955	7,599	8,267	4,911	6,419	6,739	7,122	8,508
Liquid Cargo Handling	6,739	5,841	5,606	6,628	5,797	6,537	4,905	5,725	4,649
Electronic Navigation Devices	7,507	7,503	7,786	7,391	7,157	7,831	6,292	6,494	6,443

The normalized standard decision matrix generated using the total square values of the columns and Table 11 presents the decision matrix.

Table 11

Normalized standard decision matrix

Criteria	A	B	C	D	E	F	G	H	I
ARPA Radar	3,477	3,904	3,848	3,992	2,815	3,736	3,767	2,836	2,838
ECDIS	3,157	3,970	4,094	4,121	3,595	4,059	3,214	2,708	3,066
GMDSS	1,397	2,692	2,052	1,604	1,903	2,621	1,526	1,049	1,852
Ship Control	3,941	1,933	3,272	3,492	4,131	2,179	2,822	2,909	3,739
Environmental Display	3,408	3,144	2,810	3,237	1,312	2,071	2,588	2,997	3,865
Liquid Cargo Handling	2,229	1,694	1,529	2,081	1,829	2,148	1,371	1,936	1,154
Electronic Navigation Devices	2,766	2,796	2,950	2,587	2,788	3,082	2,256	2,491	2,216

The criteria weights determined in Table 8 were converted to normal values and multiplied by the standard decision matrix to obtain a weighted standard decision matrix, as shown in Table 12.

Table 12

Weighted standard decision matrix

Criteria	A	B	C	D	E	F	G	H	I
ARPA Radar	0,382	0,820	0,654	0,679	0,253	0,448	0,113	0,057	0,199
ECDIS	0,347	0,834	0,696	0,701	0,324	0,487	0,096	0,054	0,215
GMDSS	0,154	0,565	0,349	0,273	0,171	0,315	0,046	0,021	0,130
Ship Control	0,433	0,406	0,556	0,594	0,372	0,262	0,085	0,058	0,262
Environmental Display	0,375	0,660	0,478	0,550	0,118	0,248	0,078	0,060	0,271
Liquid Cargo Handling	0,245	0,356	0,260	0,354	0,165	0,258	0,041	0,039	0,081
Electronic Navigation Devices	0,304	0,587	0,501	0,440	0,251	0,370	0,068	0,050	0,155

The negative and positive values of the columns were calculated. The ideal solution values are included in Table 13, and Table 14 presents the negative ideal solution values.

Table 13

Ideal solution

Ideal Solution	0,433	0,834	0,696	0,701	0,372	0,487	0,113	0,060	0,271

Table 14

Negative ideal solution

Negative Ideal Solution	0,154	0,356	0,260	0,273	0,118	0,248	0,041	0,021	0,081

Proximity to the ideal solution and discrimination criteria were calculated, and the values are given in Table 15.

Table 15

Proximity to ideal solution

S1+	0,160	**S1-**	0,816	**C1**	0,836
S_2^+	0,115	S_2^-	0,872	C_2	0,884
S_3^+	0,741	S_3^-	0,248	C_3	0,250
S_4^+	0,516	S_4^-	0,610	C_4	0,542
S_5^+	0,476	S_5^-	0,552	C_5	0,537
S_6^+	0,843	S_6^-	0,132	C_6	0,136
S_7^+	0,477	S_7^-	0,449	C_7	0,485

The values in Table 15 were taken into consideration, and TOPSIS ranking was obtained for the selection of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imagery, Liquid Cargo Handling, Electronic Navigation Devices Simulators, which are compulsory for use in deck class officer training and are presented in Table 16.

Table 16

Simulator selection TOPSIS ranking

Queue	Alternatives
1	ECDIS
2	ARPA Radar
3	Ship Control
4	Environmental Display
5	Electronic Navigation Devices
6	GMDSS
7	Liquid Cargo Handling

3.3. PROMETHEE Implementation

The decision matrix for the PROMETHEE application, based on the data obtained from seafarers and mariner trainers, is presented in Table 17.

Table 17

Decision matrix

Criteria	A	B	C	D	E	F	C	H	I
A	8,417	8,865	8,893	9,181	7,192	8,622	8,130	6,929	7,291
B	8,020	8,940	9,173	9,329	8,127	8,986	7,510	6,770	7,577
C	5,335	7,361	6,494	5,820	5,914	7,222	5,175	4,213	5,890
D	8,960	6,238	8,201	8,587	8,712	6,585	7,036	7,018	8,369
E	8,332	7,955	7,599	8,267	4,911	6,419	6,739	7,122	8,508
F	6,739	5,841	5,606	6,628	5,797	6,537	4,905	5,725	4,649
G	7,507	7,503	7,786	7,391	7,157	7,831	6,292	6,494	6,443
H	8,960	8,940	9,173	9,329	8,712	8,986	8,130	7,122	8,508
I	5,335	5,841	5,606	5,820	4,911	6,419	4,905	4,213	4,649

The indifference value, absolute preference threshold, and the observation/difference values between these two values were determined, and each alternative was compared with the others. The preference indices were determined using the pairwise comparison scores after being multiplied by the criteria weights and presented in Table 18.

Table 18

Preference indices of criteria

Criteria	A	B	C	D	E	F	G
ARPA Radar	-	0,019	0,640	0,345	1,024	0,753	0,333
ECDIS	0,070	-	0,691	0,382	0,396	0,804	0,384
GMDSS	0,000	0,000	-	0,106	0,061	0,205	0,000
Ship Control	0,073	0,058	0,473	-	0,164	0,480	0,204
Environmental Display	0,023	0,029	0,385	0,120	-	0,463	0,144
Liquid Cargo Handling	0,000	0,000	0,092	0,000	0,027	-	0,000
Electronic Navigation Devices	0,000	0,000	0,306	0,142	0,126	0,419	-

Positive Phi and negative Phi values were obtained by taking the horizontal and vertical averages of the determined preference indices. Then, the net preference ranking value was determined, as presented in Table 19.

Table 19

Simulator selection PROMETHEE ranking

	Phi+	Phi-	Phi
ARPA Radar	0,405	0,028	0,377
ECDIS	0,454	0,018	0,437
GMDSS	0,062	0,431	-0,369
Ship Control	0,242	0,183	0,060
Environmental Display	0,194	0,364	-0,170
Liquid Cargo Handling	0,020	0,521	-0,501
Electronic Navigation Devices	0,165	0,177	-0,012

PROMETHEE rankings for the selection of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imagery, Liquid Cargo Handling, and Electronic Navigation Devices Simulators, which are compulsory for use in deck class officer training, were obtained and are presented in Table 20.

Table 20

Simulator selection PROMETHEE ranking

Queue	Alternatives
1	ECDIS
2	ARPA Radar
3	Ship Control
4	Electronic Navigation Devices
5	Environmental Display
6	GMDSS
7	Liquid Cargo Handling

4. THE RESULTS AND DISCUSSION

This study attempts to determine the effectiveness and acceptance of ARPA Radar, ECDIS, GMDSS, Ship Control, Environmental Imagery, Liquid Cargo Handling, and Electronic Navigation Devices Simulators, which are compulsory for use in deck class officer training, in terms of maritime trainers and to determine the most widely adopted simulator according to the specified criteria. Based on the data gathered from the experts, AHP was used to determine the weighting of the criteria, and the TOPSIS and PROMETHEE methods were used together to compare the alternatives. The results of the study show that after the comparison of the criteria with the AHP method, it can be seen that the most important criterion is “closeness to reality (B),” followed by “usefulness to the evaluation and decision-making process (C).” When the findings obtained as a result of the TOPSIS and PROMETHEE methods are compared, it can be seen that the ECDIS simulator ranked first, while the ARPA Radar simulator ranked second in both methods. It can be seen that the rankings of Ship Control, GMDSS, and Liquid Cargo Handling simulators are the same in both methods. Electronic Navigational Instruments ranked 5th in the TOPSIS method, and the Environmental Imagery simulator ranked 4th, while it can be seen that it is in the opposite order in the PROMETHEE method.

In their study, [18] found that “closeness to reality” is the most important criterion. As a result of our study, the criterion that has the most important priority is “closeness to reality”, and the meaning of fact that this criterion is the most important criterion for mariner trainers in ship simulators is that it is important for the people who will work on ships to receive training in a simulator environment that is one-to-one compatible with the devices they will use on the ship. Because seafarer trainers are also seafarers with long-distance qualifications who have worked on ships, they attach importance to the compatibility of simulators with the electronic navigation devices used on ships based on their experience. Since it is advantageous for seafarers to have similar or even the same devices that they use in the simulator training they receive in the classroom environment and the devices they will use when they go on board, it is very meaningful that the criterion of “closeness to reality” is important. When producing simulators for use in maritime education, it would be more accurate to produce simulators with similar or even the same usage as the simulator used in real ships. As can be seen from the results, even though the purposes of use are diverse, people attach great importance to the fact that the devices they use are close to real life. In their smartphone study, Ref. [26] found that the “design esthetics” criterion is among the most important criteria. Since the devices in our study are not everyday devices such as smartphones that consumers will use but devices used in professional life, it is meaningful that the degree of importance is different.

Design esthetics is the least important criterion because the function of simulators, such as ECDIS or ARPA simulators, is more important than the aesthetics of their appearance. In the TOPSIS and PORMETHE methods, where the most suitable simulators were ranked according to 8 criteria such as ease of use, closeness to reality, usefulness in the evaluation and decision-making process, success in the learning process, effectiveness in teamwork, success for the relevant application, habit, design esthetics and enjoyment, it was revealed that the top three simulators were ECDIS, ARPA Radar, and Ship Control, respectively. According to these findings, it can be concluded that simulator manufacturers should be more sensitive to the production of these simulators.

5. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

This study determined the effectiveness of simulators used in maritime training the criteria for which users accept simulators, and which simulators are adopted more according to these criteria. This study will make an important contribution to the literature since there are rare studies that determine the effectiveness of simulators used in maritime education by maritime instructors. In addition, the findings obtained in this study will eliminate the lack of information on the application of simulators in maritime education, contribute to strategic planning and development programs for the application of technology in maritime education, and provide a significant road map to improve education standards in the marine sector and encourage more effective education practices. The most important limitation of this study is that it was conducted using data obtained from Turkish maritime educators and simulators used in Turkey.

Since the realism criterion is the most important criterion, it is important for simulator manufacturers to take this criterion into consideration as a priority target when making software and hardware improvements. It is of utmost importance for educational institutions to cooperate with simulator manufacturers to update existing systems to improve training processes, optimize the use of simulators for maritime education, and provide more realistic scenarios for trainees. Moreover, since the ECDIS simulator was found to be the most effective tool, it can be concluded that this simulator should be emphasized in the curriculum, training hours should be increased, the variety of scenarios suitable for real life should be expanded, and simulator-oriented practical exams should be integrated. At the same time, the consistency of the rankings made by the TOPSIS and PROMETHEE methods makes it a reliable guide for educators and decision-makers in the selection of simulators. Thus, educational institutions in the maritime sector will be able to make their training processes more effective and efficient by identifying the simulators that will contribute more to the learning process and will be able to provide well-equipped seafarers to the sector.

In future studies, other factors such as technical infrastructure, training content, user experience, environmental conditions, psychological factors and other factors affecting the effectiveness of simulators used in maritime education can be investigated. Research on the differences in simulator training between different educational institutions, how various types of simulators meet training needs, the effects of different simulator software on education and training, and the relationship between the effectiveness and acceptance of simulators and students' long-term performance and career success will contribute to the literature. In addition, research on the effectiveness and efficiency of AR, VR, or artificial intelligence-supported simulators is an important research topic that will contribute to this field.

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ОЦІНЮВАННЯ ЕФЕКТИВНОСТІ ТА ПРИДАТНОСТІ СУДНОВОГО СИМУЛЯТОРА МОРСЬКИМИ ІНСТРУКТОРАМИ

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Анотація. Технології та розроблені на їх основі технологічні пристрої стали невід'ємною частиною нашого повсякденного життя. Технології симуляторів вже багато років широко використовуються в морській освіті, дозволяючи студентам-морякам розвивати свої морські навички без необхідності мати реальний досвід роботи на судні. У такий спосіб вони можуть випробувати сценарії, які не можуть бути випробувані в реальному житті через безпекові, економічні та етичні обмеження. Це дослідження має на меті визначити ефективність і прийнятність тренажерів ARPA Radar, ECDIS, GMDSS, управління судном, візуалізації навколишнього середовища, обробки наливних вантажів, електронних навігаційних пристроїв, що використовуються в морській підготовці, з точки зору морських інструкторів. Крім того, у дослідженні поставлено мету виявити, який тренажер є найбільш прийнятним відповідно до визначених критеріїв. Дослідження вивчає вплив дизайну та функціональності тренажерів на навчальний процес, а також оцінює ефективність тренажерів для підвищення якості морської освіти та надання економічно ефективних рішень, що відповідають галузевим потребам. Дані дослідження були зібрані за допомогою методу анкетування, а рівні важливості критеріїв були розраховані за допомогою Методу аналізу ієрархій (МАІ). У дослідженні альтернативи порівнювалися за допомогою методів TOPSIS та PROMETHEE. Було визначено, що найбільш важливим критерієм є «близькість до реальності», а найменш важливим – «естетика дизайну», і в рейтингу тренажерів, які відповідають критеріям, симулятор ECDIS посів перше місце. На противагу цьому, симулятор ARPA Radar посів друге місце. Видно, що рейтинг симуляторів управління судно GMDSS та обробки наливних вантажів є однаковим для обох методів. Це дослідження є внеском у морську літературу, оскільки воно виявляє рівні важливості критеріїв, що визначають ефективність тренажерів, які використовуються для підготовки моряків палубного класу, і визначає найкращі тренажери відповідно до цих критеріїв. Новизна цього дослідження полягає в тому, що воно є внеском в обмежену кількість досліджень з оцінки морськими інструкторами в морському секторі ефективності тренажерів. У той час, як неадекватно розроблені тренажери негативно впливають на навчальний процес і перешкоджають розвитку професійних навичок, ефективні та прийнятні тренажери відіграють вирішальну роль у підвищенні якості морської освіти та наданні економічно ефективних рішень, що відповідають потребам сектору.

Ключові слова: морська освіта; судновий тренажер; МАІ; TOPSIS; PROMETHEE.