Maritime Research and Technology
MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.2.1333

Reducing Human-Error-Related Maritime Accidents Via Simulation-Based Training: An Empirical Investigation

Dina Mahgoub [(1)], Sameh Farahat [(2)], and Said Abdelkader [(3)]

[(1)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), Integrated Simulators Complex (ISC), Egypt.
[(2)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), Maritime Postgraduate Studies Institute (MPI), Egypt.
[(3)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), College of Maritime Transport and Technology (CMTT), Egypt.

Emails: dinamahgoub@hotmail.com, samehfarahat65@hotmail.com, abdelkader500@hotmail.com

Received: 05 May 2025 Accepted: 24 September 2025 Published: 13 November 2025

Abstract

Newly developed simulators have been designed based on very high and intelligent technology, thus becoming more realistic than ever before. The variety in ship models and the diversity in scenarios and critical situations they encounter have made the simulators a unique training practice. Maritime accidents associated with their severe consequences represent a real threat to the maritime transport industry, thus to maritime safety in general. Human Error Factors (HEFs) are considered to be the main contributors to those accidents, as confirmed through the literature. Therefore, this study empirically investigates how to reduce HEF-based accidents through Simulation-Based Training (SBT), and examines the extent to which this will affect the maritime safety level.

Purpose: *This Paper aims to study and investigate the role of SBT in reducing human error factor-based accidents, thus increasing the maritime safety level.*

Approach/Design/Methodology: *The Paper presents an empirical investigation into the role of SBT in reducing human error factor-based accidents that affect the maritime safety level. The study depends on collecting primary data through specially designed 30 scenario-based experiments, covering three main SBT types: Bridge Resource Management (BRM), Ship Handling (SH), and Dynamic Positioning (DP). The scenarios targeted 120 maritime experts working in the field. 26 HEFs were assessed through the different scenarios. A paired T-test was conducted to identify if there is a significant difference in the participants' performance before and after the debriefing process through SBT. Then, correlation and regression analyses were conducted to examine the relationship between those HEFs and the maritime safety level.*

CC BY NC
Copyright © 2025, authors

Findings: *Based on the scenarios' assessment checklists, it is confirmed that there is a significant improvement in the participants' performance through SBT. Correlation and regression analysis findings have partially supported the relationship between the 26 HEFs and maritime safety level.*

Recommendations: *The findings of this Paper could serve as a milestone for further studies to assess more factors that contribute to the occurrence of maritime accidents. The practical contribution of this endeavor is to provide experts and decision makers in the maritime field with a model of the most significant HEFs that have a strong impact on maritime safety.*

Keywords:

Simulation-Based Training (SBT), Human Error Factors (HEFs), Maritime safety, Maritime accidents.

1. Introduction

The maritime transport industry faces significant safety challenges due to complex operations and an unpredictable marine environment (Arslan et al., 2016). According to Maritime NZ (www.maritimenz.govt.nz), a marine accident means an occurrence that involves a ship and in which a person is seriously harmed and/or the ship sustains damage or structural failure, and an incident means any occurrence, other than an accident, that is associated with the operation of a ship and affects or could affect the safety of operation. A variety of human errors impair the performance of maritime operators; these faults are the primary cause of several incidents. The Costa Concordia disaster of 2012 is one of the famous naval disasters that reflects the impact of HEF, where the ship wrecked just off the coast of an Italian island in relatively shallow water. The disaster killed 32 people and seriously injured many others (en.wikipedia.org). Oluseye and Ogunseye (2016) identified nine major human-related factors as major causes of accidents: poor crew interaction, crew fatigue, drug and alcohol use, unsafe vessel speed, commercial pressure from management, complicated work processes, knowledge gaps, faulty crew judgment, and unruly behavior.

Hontvedt (2015) has highlighted some important human elements, including exhaustion, lack of situational awareness, lack of collaboration, and poor decision-making, that are frequently linked to shipping accidents. Even while the significance of human variables in accidents is acknowledged, it is unclear how effective training to combat these elements might be.

It is argued that the primary cause of marine incidents is a lack of acceptable working attitudes, sense of responsibility, mutual cooperation, and appropriate Bridge Resource Management (BRM) on the part of seafarers. On the one hand, in some accident scenarios, the crew lacks even the most basic professional ethics. On the other hand, some individuals believe that if the shipping company's crew is well-versed in operating rules and regulations, the ship's safety and operational benefits will be secured. In that circumstance, future soft skill development is required (Zhang, 2017).

Based on their activities, human mistakes may be divided into two categories: intentional and unintentional. Mistakes that happen accidentally and often in routine tasks that are carried out so frequently that they become automatic are known as unintentional action mistakes. These mistakes are separated into memory impairment and slips. On the other hand, there are two types of intended action errors: mistakes and violations. Errors happen when, in spite of a sincere effort to stick to protocols, a decision-making error leads to the application of an improper rule. Therefore, by enhancing supervision, training, and the quality of procedural documentation, roles and knowledge-based mistakes may be minimized from this category (Al-Shammari and Oh, 2018).

According to the European Maritime Safety Agency report, human factors were the main reason behind most of the maritime accidents that occurred from 2014 until 2020 (EMSA, 2021). Furthermore, the navigation accidents assessment conducted by EMSA in 2022 revealed that nearly 78% of the navigation incidents that have been investigated had some sort of "human factor" component. By focusing on the intricacy of human mistakes, it was demonstrated that marine casualty is not explained by the variability of the major actors' performance. On the other hand, human activity results from complex, non-linear, and dynamic socio-technical interactions between individuals onboard, organizations onshore, policies, procedures, and machinery (EMSA, 2022).

The distribution of contributing factors for the period from 2014 to 2022 determines the percentage of contributing factors and is organized by contributing factor types and accident event types, as shown in Figure 1 (EMSA, 2023). Shipboard operation is the most important contributing factor type, with 69.9% of all the contributing factors, while shore management with 23.2%, and external environment with 6.9%. The figure also emphasizes that 'Human action' is the main accident event type, with 67.6% of all the contributing factors, followed by 'System/equipment failure' with 19.7% of all the contributing factors.

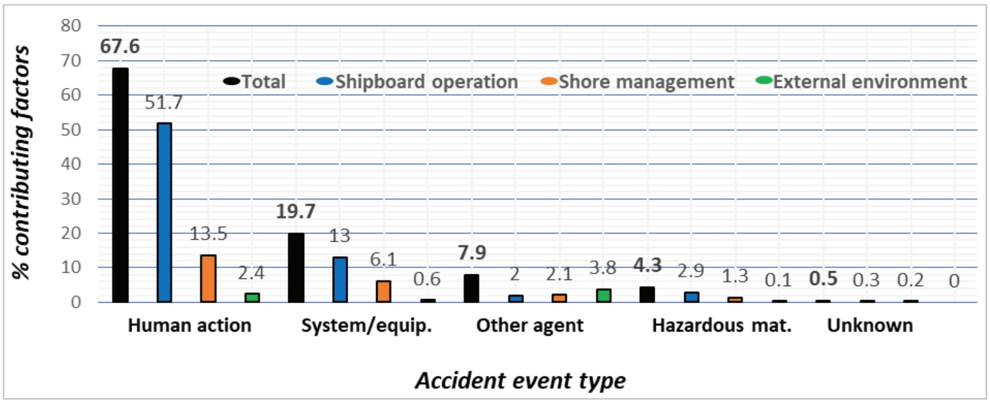

Figure 1: Percentage of contributing factors for the period 2014-2022 (EMSA, 2023).

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.2.1333

Through a systematic examination of these Human Error Factors (HEFs) through Simulation-Based Training (SBT) technique, this paper endeavors to clarify the complicated interplay between human actions and maritime safety level. This study aims to provide valuable insights for industry stakeholders, regulatory bodies, and maritime professionals regarding how SBT could have an effective impact on those HEFs by reducing their potential in the future while enhancing the participants' performance. Therefore, understanding human error factors is essential for enhancing maritime safety by reducing the rate of maritime accidents.

While significant strides have been made in understanding the complicated relationship between human error and maritime safety, there still exists a noticeable research gap regarding the comprehensive examination of specific human error factor groups and their collective impact on maritime safety level, especially through an empirical methodology. The existing body of literature often addresses isolated aspects of human error in maritime contexts, but this study is investigating five different HEF groups and their impact on maritime safety level through an empirical investigation, "Scenario-Based Experiment" via Simulation-Based Training (SBT).

Simulators are useful teaching and training tools for the maritime industry. Simulators can support the development of knowledge, abilities, and proficiency across a range of levels of accountability, from standard shipboard operations to challenging performances, responsibilities, and tasks. Simulator training can help trainees apply their knowledge from the training to real-world circumstances (Maung, 2019). Simulation technology enables officers and masters to practice navigational skills and see how ships behave and react in a risk-free environment. The ability to replay task performance provides extensive feedback and conversations, as well as gives educators the chance to modify the training material and track and evaluate the participants' progress. Additionally, the usage of simulators could make it easier for trainees to practice non-technical abilities (Kim et al., 2021).

The integrated transportation system, meanwhile, depends on sea transit. Additionally, a variety of mishaps, such as ship collisions and groundings, regularly cause significant environmental damage, monetary losses, and deaths. As a result, one of the most important study topics for water transportation is maritime safety (Xue et al., 2021). Therefore, the urgency of this Paper lies in its potential to identify more accurately the human error factors that have a significant impact on marine accidents; thus, on the maritime safety level, in order to study the suitable preventive actions to reduce them in the future. From this Paper's perspective, SBT could help to reduce the potential of those HEFs through effective training programs, also to guide participants regarding how to behave in a professional manner during emergencies and critical situations, and how they can gain more knowledge and experience through accredited experienced instructors, in order to avoid such risks in real life. The findings of this study have the potential to significantly contribute to the overall safety and elasticity of maritime operations, ensuring the well-being of maritime personnel, the protection of valuable cargo, and the sustainability of global trade.

2. Methodology

This study is based on an empirical approach, where 30 scenario-based experiments concerning three types of simulation training: Bridge Resource Management (BRM), Ship Handling (SH), and Dynamic Positioning (DP), will be conducted on 120 maritime trainees (officers, masters, and pilots) working in the industry. The trainees will be assigned 30 different challenging scenarios with variant emergency situations, to examine and assess their performance regarding 26 human error factors that have been embedded in the scenarios' design in order to assess their performance before and after the debriefing process through the SBT technique. Based on the scenarios' result analysis, a paired T-test will be conducted for the 26 human error factors with the aim of comparing means. Also, it will be conducted for the five human error factor groups with the aim of comparing overall means for the groups. Finally, correlation and regression analysis will be conducted on the HEFs in order to test the study hypotheses and to investigate the relationship between those HEFs and the maritime safety level.

2.1. Selection of factor groups

After reviewing the diversity in HEFs' types and classifications through literature, five main HEF groups were considered, with a total of 26 factors as follows:

- **Competency Factors (CFs) group,** which includes (Technical Knowledge, Training, Skills, Attitude, Response, Experience, and Perception).
- **Team Factors (TFs) group,** which includes (Communication (EXT), Communication (INT), Team Management, Watch keeping, and Safety Awareness).
- **Psychological Factors (PSFs) group,** which includes (Risk Tolerance, Stress Resistance, Panic Resistance, and Complacency).
- **Voyage Management Factors (VMFs) group,** which includes (Passage/ Voyage Plan, Decision Making, Procedures and Checklists, Look Out, and Situation Awareness).

- **Application Factors (AFs) group,** which includes (Position Fixing, Usage of Bridge Equipment, Maneuvering, Interpretation Adequacy, and Ship Speed).

It is important to mention here that the selection of factors and groups has been discussed in detail in a previous study (Mahgoub et al., 2024). The study hypotheses assume that there is a strong correlation between each of the independent variables (5 HEF groups) and the dependent variable (Maritime Safety Level), i.e., the more one can control and reduce those human factors leading to errors and narrow the gap of its potential causes, thus decreasing marine accidents rate, the higher maritime safety level could be achieved. This will be done through the effective adoption of SBT.

2.2. Integrated Simulators Complex (ISC) at the AASTMT

Integrated Simulators Complex (ISC) in the Arab Academy for Science, Technology and Maritime Transport (AASTMT) is a prominent specialized entity in the field of Maritime training and consultation by using the top-of-the-line simulators since 1996. The ISC will provide its latest technology in the Full Mission Ship handling Simulator (FMSS) class (A) by Wärtsilä (TRANSAS) with 360° of visualization, as well as the DP2 Full Mission Offshore Vessel Simulator class (A) by ARI, with 360°, to use their capabilities and training facilities in order to conduct this empirical study.

2.3. Scenario-Based Experiment via SBT

Thirty different scenarios/maneuvers (scenario-based experiments) with various difficulty levels of unfamiliar and emergency situations are designed to test and assess the trainees' performance before and after the debriefing process via SBT. Effective SBT should be accompanied by an adequate debrief given by senior instructors to demonstrate the participant's mistakes that led to such accidents and to ensure the optimum performance for each scenario after debriefing. In so doing, human error factors related to marine accidents are identified and measured more accurately.

Three types of SBT are targeted in this study, which are: BRM, SH, and DP. Each type includes 10 different scenarios with a total of 30 scenarios. Every single scenario has been assessed twice, the first one is done before the debriefing process provided by the accredited experienced instructor/assessor, and the second one is done after debriefing and the effective training through SBT.

Table 1 represents the 30 specially designed scenario-based experiments regarding BRM, SH, and DP through the SBT technique.

Table 1: Scenario-based experiments regarding BRM, SH, and DP.

a	b	c	d	e	f
BRM Code	**Scenario Description**	**SH Code**	**Scenario Description**	**DP Code**	**Scenario Description**
BRM 1	Singapore Port Unberthing from Singapore Tanker Terminal and proceeding to Malaysia	**SH 1**	Aden Port Berthing Tanker on jetty #3 at Tanker Terminal	**DP 1**	Diving Operation Emergency Failure: Position Reference Failure (PRF)
BRM 2	Port Said Port Berthing Bulk carrier at Bulk Terminal inside Port Said Harbor, passing through Old Suez Channel	**SH 2**	Aden Port Berthing on jetty #2 (AZIMUTH propeller)	**DP 2**	Remote Operating Vehicle (ROV) Emergency Failure: Power Failure
BRM 3	Port Said Port Berthing Bulk carrier at Bulk Terminal	**SH 3**	Aden Port Unberthing from jetty #1 from Container Terminal	**DP 3**	Diving Operation Emergency Failure: Position Ref. Failure "Fan Beam"
BRM 4	El Sukhna Port Unberthing the Cargo ship	**SH 4**	Damietta Port Berthing a Huge Container on jetty #6 at Container Terminal	**DP 4**	ROV Follow Operation Emergency Failure: Switch Board / Power Failure
BRM 5	Damietta Port Berthing LNG on jetty #2 at Gas Terminal	**SH 5**	Aden Port Berthing on jetty #2 at Container Terminal	**DP 5**	Diving Operation Emergency Failure: Failure in Sensors in addition to PRF
BRM 6	Alexandria Port Berthing a Huge Container at Container Terminal	**SH 6**	El Sukhna Port Berthing vessel on dock (Bow in)	**DP 6**	ROV Follow Operation Emergency Failure: Thruster Failure in addition to Power Failure

BRM 7	El Sukhna Port Berthing vessel on the dock, St/rd alongside	**SH 7**	Damietta Port Unberthing the Cargo ship	**DP 7**	Diving Operation Emergency Failure: Failure in the sensors "GYRO"
BRM 8	Singapore Port Unberthing from Singapore Tanker Terminal	**SH 8**	Alexandria Port Berthing Tanker at Petroleum Terminal	**DP 8**	ROV Follow Operation Emergency Failure: Failure in the thrusters
BRM 9	Aden Port Berthing on the jetty at Container Terminal	**SH 9**	Port Said Port Berthing Bulk carrier at Bulk Terminal	**DP 9**	Diving Operation Emergency Failure: Failure in sensors in addition to the PRF "Artemis 1"
BRM 10	Alexandria Port Unberthing the Bulk carrier from Bulk Terminal	**SH 10**	Alexandria Port Berthing Tanker at Petroleum Terminal	**DP 10**	ROV Follow Operation Emergency Failure: Thruster Failure in addition to Power Failure

3. Results

3.1. Pair T-test analysis

Table 2 shows a paired T-test analysis that has been conducted on the 5 HEF groups and the 26 HEFs based on the trainees' empirical assessment results through the 30 simulation training scenarios, before and after the debriefing process. It shows that the mean value for each HEF group and also for each individual factor is obviously increased after debriefing, which means that there is an obvious improvement in trainees' performance after the debriefing process, as the corresponding P-values are less than 0.05. Also in Table 2, HEF groups and factors are ranked based on their improvement %.

Table 2: Pair T-test analysis for the: (a) 5 HEF groups and (b) 26 HEFs, ranked upon their improvement %.

a	b	c	d	e	f	g
Pair #	**(a) Human Error Factor Group**	**Status**	**No. of scenarios**	**Mean value**	**P-Value**	**Improvement %**
Pair 1	Competency Factors Group	Before	30	0.233	0.000	**66.2**
		After	30	0.895		
Pair 2	Voyage Management Factors Group	Before	30	0.250	0.000	**63.7**
		After	30	0.887		
Pair 3	Team Factors Group	Before	30	0.266	0.000	**63.0**
		After	30	0.896		
Pair 4	Application Factors Group	Before	30	0.305	0.000	**51.6**
		After	30	0.821		
Pair 5	Psychological Factors Group	Before	30	0.370	0.000	**37.0**
		After	30	0.740		
Pair #	**(b) Human Error Factor (HEF)**	**Status**	**No. of scenarios**	**Mean value**	**P-Value**	**Improvement %**
Pair 1	Training	Before	30	0.153	0.000	**81.4**
		After	30	0.967		
Pair 2	Experience	Before	30	0.163	0.000	**80.4**
		After	30	0.967		
Pair 3	Response	Before	30	0.155	0.000	**78.8**
		After	30	0.943		
Pair 4	Decision Making	Before	30	0.143	0.000	**78.7**
		After	30	0.930		
Pair 5	Stress Resistance	Before	30	0.163	0.000	**75.4**
		After	30	0.917		

Pair 6	Situation Awareness	Before	30	0.177	0.000	**72.0**
		After	30	0.897		
Pair 7	Safety Awareness	Before	30	0.175	0.000	**71.4**
		After	30	0.889		
Pair 8	Team Management	Before	30	0.257	0.000	**67.6**
		After	30	0.933		
Pair 9	Panic Resistance	Before	30	0.190	0.000	**66.7**
		After	30	0.857		
Pair 10	Passage/ Voyage Plan	Before	30	0.290	0.000	**65.7**
		After	30	0.947		
Pair 11	Communication (EXT)	Before	30	0.285	0.000	**64.7**
		After	30	0.932		
Pair 12	Technical Knowledge	Before	30	0.267	0.000	**62.5**
		After	30	0.892		
Pair 13	Watchkeeping	Before	30	0.253	0.000	**57.7**
		After	30	0.830		
Pair 14	Usage of Bridge Equipment	Before	30	0.313	0.000	**57.4**
		After	30	0.887		
Pair 15	Procedures and Checklists	Before	30	0.270	0.000	**57.3**
		After	30	0.843		
Pair 16	Perception	Before	30	0.265	0.000	**56.5**
		After	30	0.830		
Pair 17	Maneuvering	Before	30	0.223	0.000	**56.0**
		After	30	0.783		
Pair 18	Skills	Before	30	0.276	0.000	**55.4**
		After	30	0.830		
Pair 19	Risk Tolerance	Before	30	0.267	0.000	**55.0**
		After	30	0.817		
Pair 20	Communication (INT)	Before	30	0.360	0.000	**53.7**
		After	30	0.897		
Pair 21	Ship Speed	Before	30	0.267	0.000	**52.3**
		After	30	0.790		
Pair 22	Position Fixing	Before	30	0.357	0.000	**52.0**
		After	30	0.877		
Pair 23	Complacency	Before	30	0.862	0.000	**49.0**
		After	30	0.372		
Pair 24	Attitude	Before	30	0.353	0.000	**47.7**
		After	30	0.830		
Pair 25	Look Out	Before	30	0.370	0.000	**44.7**
		After	30	0.817		
Pair 26	Interpretation Adequacy	Before	30	0.367	0.000	**40.3**
		After	30	0.770		

3.2. Correlation and regression testing

In this section, the hypotheses under study are tested using correlation and regression analysis. The Pearson correlation is used as the data under study are shown to be normally distributed. Correlation matrices for the relationship between the 5 HEF groups and maritime safety level have been established. Table 3 is an example that shows the Correlation matrix for the CF group and maritime safety level.

To investigate the impact of the 5 HEF groups on maritime safety level, multiple regression analysis has been done for each group. For the impact of the Competency Factors (CFs) group on the maritime safety level. It could be observed that there is a significant positive impact of response, training, and skills on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.634, 0.505, and 0.201, respectively. On the contrary, it could be observed that there is an insignificant impact of technical knowledge, experience, perception, and attitude on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.990 using training, skills, and response, as the R2 is 99%, as shown in Table 4.

For the impact of the Psychological Factors (PSFs) group on the maritime safety level. It could be observed that there is a significant positive impact of risk tolerance, complacency, and stress resistance on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.332, -0.239, and 0.756, respectively. On the contrary, it could be observed that there is an insignificant impact of panic resistance on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.970 using risk tolerance, complacency, and stress resistance, as the R2 is 97%.

For the impact of the Team Factors (TFs) group on the maritime safety level. It could be observed that there is a significant positive impact of safety awareness, watchkeeping, and team management on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.689, 0.261, and 0.243, respectively. On the contrary, it could be observed that there is an insignificant impact of communication (EXT) and communication (INT) on the maritime safety level, since the P-value was still more than 0.05. Moreover, maritime safety level could be described by 0.981 using safety awareness, watchkeeping, and team management, as the R2 is 98.1%.

For the impact of the Application Factors (AFs) group on the maritime safety level. It could be observed that there is a significant positive impact of position fixing and usage of bridge equipment on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.785 and 0.677, respectively. On the contrary, it could be observed that there is an insignificant impact of ship speed, interpretation adequacy, and maneuvering on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.925 using position fixing and usage of bridge equipment, as the R2 is 92.5%. And finally, for the impact of the Voyage Management Factors (VMFs) group on the Safety Level. It could be observed that there is a significant positive impact of passage plan, situation awareness, decision making, and procedures/ checklists on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.222, 0.731, 0.207, and 0.164, respectively. On the contrary, it could be observed that there is an insignificant impact of lookouts on the maritime safety level, since the P-value was still more than 0.05. Moreover, maritime safety level could be described by 0.975 using passage plan, situation awareness, decision making, and procedures/ checklists, as the R2 is 97.5%.

Table 3: Correlation matrix for the CFs group and maritime safety level.

Competency Factors group		Technical Knowledge	Experience	Training	Skills	Response	Perception	Attitude	Maritime Safety Level
Technical Knowledge	Pearson C.	1							
	Sig. (2-tailed)								
	N	60							
Experience	Pearson C.	.961	1						
	Sig. (2-tailed)	.000							
	N	60	60						
Training	Pearson C.	.961	.996	1					
	Sig. (2-tailed)	.000	.000						
	N	60	60	60					
Skills	Pearson C.	.939	.937	.935	1				
	Sig. (2-tailed)	.000	.000	.000					
	N	59	59	59	59				
Response	Pearson C.	.964	.974	.975	.945	1			
	Sig. (2-tailed)	.000	.000	.000	.000				
	N	60	60	60	59	60			
Perception	Pearson C.	.944	.963	.965	.922	.972	1		
	Sig. (2-tailed)	.000	.000	.000	.000	.000			
	N	60	60	60	59	60	60		
Attitude	Pearson C.	.895	.914	.914	.875	.926	.941	1	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		
	N	60	60	60	59	60	60	60	
Maritime Safety Level	Pearson C.	.971	.977	.980	.954	.991	.974	.922	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
	N	60	60	60	59	60	60	60	60

Table 4: Multiple regression of the impact of the CFs group on maritime safety level.

Model	Unstandardized Coefficients		Standardized Coefficients	Sig. P-value	R^2
	B	Std. Error	Beta		
(Constant)	-.265	.029		.000	0.990= 99%
Technical Knowledge	.178	.089	.115	.051	
Experience	-.310	.183	-.256	.097	
Training	.505	.184	.422	.008	
Skills	.201	.076	.118	.011	
Response	.634	.102	.506	.000	
Perception	.212	.117	.123	.077	
Attitude	-.038	.079	-.020	.630	
Dependent variable: maritime safety level					

4. Discussion

Based on the empirical study results, it could be observed that the trainees' performance regarding dealing with emergency situations has been improved, as demonstrated through the Pair T-test results. Also, the scenarios have been fulfilled safely through the repetition of the scenario for the second time. During the first time scenario running, trainees have made some critical errors that led to fatal accidents like ship collision and grounding. On the other side, while running the same scenario for the second time, after the debriefing had been demonstrated by senior instructors, those types of errors by trainees were obviously decreased, and no accidents occurred. Based on these assessments, a paired T-test analysis was conducted to investigate the trainees' performance to determine if there is a difference in means or if it is the same before and after the debriefing process. Results show that there is a significant difference between means for all 5 HEF groups and the 26 HEFs before and after the effective debriefing through SBT, as the corresponding P-values are less than 0.05.

In order to determine the extent of the impact of human error factors on maritime safety level, correlation and regression tests were conducted on the five groups with their 26 pertinent factors. The results firstly showed that regarding the effect of competency factors group on maritime safety level, there is a significant positive impact of Training, Skills, and Response on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Technical Knowledge, Experience, Perception, and Attitude on maritime safety level, since the P-value was still more than 0.05. Which means that the effect of the competency factors group on maritime safety level is partially acceptable.

Secondly, regarding the effect of psychological factors on maritime safety level, there is a significant positive impact of Risk Tolerance, Complacency, and Stress Resistance on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Panic Resistance on maritime safety level, since the P-value was still more than 0.05. Which means that the influence of the psychological factors group on the maritime safety level is partially acceptable.

Thirdly, the results showed that the impact of team factors group on maritime safety level is significant, with a positive impact of Safety Awareness, Watchkeeping, and Team Management on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Communication (EXT) and Communication (INT) on the maritime safety level, since the P-value was still more than 0.05. Which means that the impact of the team factors group on maritime safety level is partially acceptable.

Fourth, the results showed concerning the effect of application factors group on maritime safety level, that there is a significant positive impact of Position Fixing and Usage of Bridge equipment on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Ship Speed, Interpretation Adequacy, and Maneuvering on maritime safety level, since the P-value was still more than 0.05. Which means that the effect of the application factors group on maritime safety level is partially acceptable.

Fifth, the results showed that regarding the impact of voyage management factors group on maritime safety level, there is a significant positive impact of Passage Plan, Decision Making, Procedures and checklists, and Situation Awareness on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Look Out on the maritime safety level, since the P-value was still more than 0.05. This means that the effect of the voyage management factors group on maritime safety level is partially acceptable.

5. Conclusion

The empirical study results have emphasized the role of SBT in reducing the occurrence of maritime accidents through enhancing the performance and skills of trainees. This was confirmed through the 30 scenarios that have been executed after debrief. Furthermore, the pair T-test analysis' results have confirmed the improvement rate of participants' performance before and after the SBT effective debriefing provided by senior instructors; correlation and regression analysis' results have emphasized the same findings, and, moreover, the most significant HEFs that have a strong impact on maritime safety level have been identified as follows: position fixing, stress resistance, situation awareness, safety awareness, usage of bridge equipment, response, training, risk tolerance, watchkeeping, team management, complacency, passage plan, decision making, skills, and procedures/checklists.

It is also verified through Pair T-test analysis that the competency factors group is the group that has been improved the most after debrief, followed by the voyage management factors group, then the team factors group, the application factors group, and finally the psychological factors group, as shown in Figure 2.

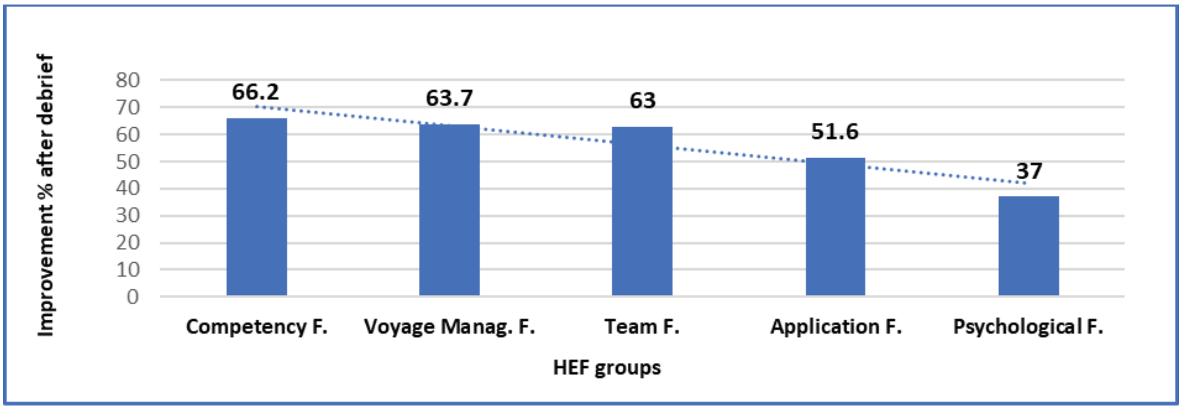

Figure 2: Percentage HEF groups' improvement after debriefing.

Regarding the HEFs, the study has concluded that the lack of training, inadequate experience, late response and decision making, mismanagement during panic and stress, lack of situation and safety awareness, inefficient team management, lack of communication skills and technical knowledge, and the misperception of emergency situations are the most important human error factors that have a significant impact on maritime accidents. Therefore, Maritime Education and Training (MET) should focus more effectively on the improvement of seafarers' technical and non-technical skills as mentioned.

The study results could help the decision makers to adopt the most suitable solutions to neutralize those factors and to subsequently enhance the skills and performance of seafarers towards achieving higher safety levels. However, the results reported herein cannot be generalized without taking the limitations encountered during conducting this study into consideration.

Three such limitations were dictated; firstly, this research took place at the Arab Academy for Science, Technology, and Maritime Transport in Egypt. Therefore, it is suggested to conduct similar studies in other universities in developed countries, on a larger scale of participants, in order to provide a comparative study between the results of developing and developed countries. Secondly, the empirical study has covered only three types of SBT scenarios (BRM, SH, and DP), so it is recommended to investigate more factors, such as mechanical failures, environmental and weather conditions, through other SBT types, such as natural gas and petrochemicals handling simulation, environment protection, and crisis management simulation. Thirdly, this research has covered only specific types of maritime accidents, which are: vessel collision and grounding regarding BRM and SH, loss of DP capability regarding two main DP operations, i.e., diving and ROV operations. Therefore, it is strongly suggested to conduct more scenarios to cover further areas related to maritime accidents.

Lastly, the current study was compared with similar studies of other investigators as follows: Ziaul et al. (2023) identified through the intensive review of literature some factors that have been mostly assessed through the simulation scenarios/exercises; as per this study did (Situation awareness, usage of bridge equipment "Radar and ECDIS", watchkeeping, maneuvering, dynamic positioning, and decision making), but it is important to mention here that this study has assessed 26 factors regarding five different groups, which made the results of this study more accurate after assessment. Also, data collection approaches were almost the same, including simulator data, video recording, voice recordings, and monitoring through specialized cameras. The comparison also assured that the mean comparison tests, like the Pair T-test analysis, which is used in this study, were the most common analysis methods used in similar studies. Moreover, this study has used more than one analytical tool, as it used Pair T-test analysis, correlation, and regression analysis, which support this endeavor's findings and results.

Authors' response to reviewers' comments on the Paper entitled:

"Reducing Human-Error-Related Maritime Accidents Via Simulation-Based Training: An Empirical Investigation"

#	1st Reviewer (A) Comments	Response
1	Refer to the Costa Concordia disaster of 2012.	- Done as requested.
2	Add the abbreviation (BRM) to Bridge Resource Management.	- Abbreviation has been added.
#	**2nd Reviewer (B) Comments**	**Response**
(A1)	Abstract: To be shortened and merged with the purpose.	- Abstract has been shortened. - According to MRT journal rules, the Abstract is separated from the purpose.
(A2)	Introduction: Introduction is missing.	- Introduction has been added.
(A3)	Define accident and incident.	- Definitions have been added.
(A4)	Paraphrase the statement to be more academic.	- Statement has been paraphrased.
(A5)	Paraphrase the statement to be more academic.	- Statement has been paraphrased.
(A6)	Source please.	- Source is EMSA, 2023, as indicated in the caption of Figure 1.
(A7)	Make it shorter and move it to the introduction.	- Paragraph has been shortened and moved to the introduction.
(A8)	Insert reference.	- This paragraph is related to this Paper, the author mentions here the selected human error factor groups that the study has adopted, to investigate their impact on maritime safety level through an empirical investigation.
(A9)	Insert reference.	
(A10)	Replace with simulators.	- Done as requested.
(A11)	Insert reference.	- Reference has been added.
(A12)	What is your existing theory? What are the hypotheses?	- Changes have been made (Paragraph 1 under Methodology; page 4). - Hypothesis has been mentioned (Last paragraph; page 4).
(A13)	Should provide the tests of Correlation and Regression Testing.	- Tables 3 and 4 have been added as a sample for Correlation and Regression Testing.
(A14)	Very long conclusion.	- Conclusion has been summarized as possible.

References

Arslan, V., Kurt, R.E., Turan, O. and De Wolff, L. (2016), "Safety Culture Assessment and Implementation Framework to Enhance Maritime Safety", *Transportation Research Procedia*, Vol. 14, pp. 3895–3904, doi: 10.1016/j.trpro.2016.05.477.

Chan, S.R., Hamid, N.A. and Mokhtar, K. (2016), "A Theoretical Review of Human Error in Maritime Accidents", *Advanced Science Letters*, Vol. 22 No. 9, pp. 2109–2112, doi: 10.1166/asl.2016.7058.

Dominguez-Péry, C., Vuddaraju, L.N.R., Corbett-Etchevers, I. and Tassabehji, R. (2021), "Reducing maritime accidents in ships by tackling human error: a bibliometric review and research agenda", *Journal of Shipping and Trade*, Vol. 6 No. 1, p. 20, doi: 10.1186/s41072-021-00098-y.

European Maritime Safety Agency (EMSA). (2021), "Marine Casualties and Incidents: Preliminary Annual Overview of Marine Casualties and Incidents 2014-2020", November.

European Maritime Safety Agency (EMSA). (2022), "Safety Analysis of EMCIP Data: Analysis of Navigation Accendents – Summery Report", November.

European Maritime Safety Agency (EMSA). (2023), "Annual Overview of Marine Casualties and Incidents."

Fan, S. (2020), *Human Factors in Maritime Transportation and Mental Workload Analyses for Seafarers in Bridge Simulation*, Liverpool John Moores University , United Kingdom.

FSH Al-Shammari, N. and Oh, J.-S. (2018), "Effects Of Human Error On Marine Safety: Case Study", *Journal of Engineering Research and Application Www.Ijera.Com*, Vol. 8.

Hontvedt, M. (2015), "Professional vision in simulated environments — Examining professional maritime pilots' performance of work tasks in a full-mission ship simulator", *Learning, Culture and Social Interaction*, Vol. 7, pp. 71–84, doi: 10.1016/j.lcsi.2015.07.003.

Ismila Che Ishak, Mohamad Fitri Azlan, Shaiful Bakri Ismail and Norhayati Mohd Zainee. (2019), "A STUDY OF HUMAN ERROR FACTORS ON MARITIME ACCIDENT RATES IN MARITIME INDUSTRY", *Asian Academy of Management Journal*, Vol. 24 No. Supp. 2, pp. 17–32, doi: 10.21315/aamj2019.24.s2.2.

Kim, T., Sharma, A., Bustgaard, M., Gyldensten, W.C., Nymoen, O.K., Tusher, H.M. and Nazir, S. (2021), "The continuum of simulator-based maritime training and education", *WMU Journal of Maritime Affairs*, Vol. 20 No. 2, pp. 135–150, doi: 10.1007/s13437-021-00242-2.

Kretschmann, L. (2020), "Leading indicators and maritime safety: predicting future risk with a machine learning approach", *Journal of Shipping and Trade*, Vol. 5 No. 1, doi: 10.1186/s41072-020-00071-1.

Liu, Y., Hou, X., Sourina, O., Konovessis, D. and Krishnan, G. (2016), "Human factor study for maritime simulator-based assessment of cadets", *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, Vol. 3, doi: 10.1115/OMAE2016-54772.

Mahgoub, D.F., Farahat, S. and Abdelkader, S. (2024), "Identification and prioritization of human error factors related to maritime accidents", *Maritime Research and Technology*, Vol. 3 No. 2, p. 77, doi: 10.21622/MRT.2024.03.2.913.

Maung, C.T. (2019), *Simulation Training and Assessment in Maritime Education and Training.* , Masters' Thesis, World Maritime University, Malmö. Sweden.

Munim, Z.H., Krabbel, H., Haavardtun, P., Kim, T.E., Bustgaard, M. and Thorvaldsen, H. (2023), "Scenario Design, Data Measurement, and Analysis Approaches in Maritime Simulator Training: A Systematic Review", *Lecture Notes in Networks and Systems*, Vol. 769 LNNS, doi: 10.1007/978-3-031-42134-1_4.

Oluseye, O. and Ogunseye, O. (2016), "Human Factors as Determinants of Marine Accidents in Maritime Companies in Nigeria", *British Journal of Education, Society & Behavioural Science*, Vol. 18 No. 4, doi: 10.9734/bjesbs/2016/29548.

Reza Emad, G. and Kataria, A. (2022), "Challenges of simulation training for future engineering seafarers - A qualitative case study", doi: 10.54941/ahfe1002501.

Uğurlu, Ö., Köse, E., Yıldırım, U. and Yüksekyıldız, E. (2015), "Marine accident analysis for collision and grounding in oil tanker using FTA method", *Maritime Policy and Management*, Vol. 42 No. 2, doi: 10.1080/03088839.2013.856524.

Xue, J., Papadimitriou, E., Reniers, G., Wu, C., Jiang, D. and van Gelder, P.H.A.J.M. (2021), "A comprehensive statistical investigation framework for characteristics and causes analysis of ship accidents: A case study in the fluctuating backwater area of Three Gorges Reservoir region", *Ocean Engineering*, Vol. 229, p. 108981, doi: 10.1016/j.oceaneng.2021.108981.

Zhang, W. (2017), "Assessing the competency of seafarers using simulators in bridge resource management (BRM) training", *World Maritime University Dissertations.*