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Enhancing Safety of Navigation with ECDIS Standardization and S-Mode Adoption

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ABSTRACT

The International Maritime Organization (IMO) has encouraged flexibility in the design of an Electronic Chart Display and Information System (ECDIS), resulting in a variety of capabilities, interfaces and functions. However, this diversity can create challenges in consistently presenting, interpreting and using critical navigational data, increasing the potential for navigational errors. The study explores the implementation of S-Mode, a standardized user interface for navigation equipment, to enhance situational awareness, safety and operational efficiency in maritime navigation. A quantitative survey was conducted with 417 deck officers who have experience with ECDIS of various types onboard ships. The study used Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) to analyze the data and evaluate the research hypotheses with descriptive analysis for research variables and participant profiles using AMOS and SPSS software, focusing on how the ease of use and usefulness of S-Mode influences its adoption among maritime professionals. The findings indicate that introducing S-Mode significantly improves responsiveness, information credibility, and operations quality, meeting critical navigational needs more effectively.

The SEM analysis also showed that S-Mode reduces human error and facilitates recognition of different ECDIS models, highlighting the role of the interface in enhancing safety and efficiency. The study concludes by emphasizing the need for continuous and specialized type-specific training for ECDIS systems and advocates for establishing industry-wide standards in interface design to ensure consistency and safety in maritime navigation.

Key-words:
ECDIS, S-Mode, Standardization, Safe Navigation, Perceived Usefulness, Training.

INTRODUCTION

Over the past 20 years, the IMO has given ECDIS manufacturers greater flexibility in terms of equipment capacity, software interfaces and additional features. This has led to significant variations between ECDIS models. However, these differences in how important information is shared, understood and used have increased the risk of catastrophic accidents due to improper use of equipment. To ensure that navigational officers have faster access to essential data and features that support safe navigation, improving ECDIS standards is essential. Until then, the industry should prioritize comprehensive, targeted specific standard training and ongoing skills development. This will ensure that all officers are fully aware of the system limitations and capabilities, enabling its intended operation and reducing the potential for accidents due to human error (IMO, 2019).

The IMO mandates Standards of Training, Certification, and Watchkeeping (STCW) for masters and officers in charge of navigational watches on ships equipped with ECDIS. To meet the 2010 Manila Amendments to the STCW Convention and Code, these officers must complete general ECDIS training. According to STCW Convention regulation I/14, masters and officers serving on ships with ECDIS must familiarize themselves with the ship equipment, including ECDIS, as outlined in the Guidance for Good Practice (IMO, 2022). Before taking control of navigational watches, operators should receive type-specific training to develop the skills needed to operate the onboard ECDIS, including its backup setup (NI, 2012; AMSA, 2017). While deck officers are trained and familiarized with ECDIS operations, including ENCs, chart symbols, safety contours, no-go zones, and passage planning procedures, maintaining ECDIS competency remains challenging (Weintrit, 2022).

The Maritime Safety Committee issued, in session No. 86 of 2009, new instructions for installing the Electronic Chart System (ECS) on ships, starting in July 2012, according to the type and load of each ship. The gradual start of ships relying on ECDIS systems as an essential means of navigation has led to the emergence of fundamental defects in the systems that directly affect the safety of maritime navigation. Therefore, the International Hydrographic Organization has issued a set of tests to identify and study these defects until they are eliminated (Lawson, 2018) by scientific methods and approaches with the companies that manufacture these systems to raise their degree of reliability to increase the level of maritime navigation safety and preserve the marine environment. With the entry into force of the ECDIS system and the reliance of many ships on electronic maps instead of paper maps, it is time for the authorities responsible for maritime navigation safety in the Arab Republic of Egypt to take the necessary and vital measures to ensure the safety of navigation on the Egyptian coasts, including, but not limited to, raising the efficiency of surveying maps on the Egyptian coasts and issuing instructions and guidelines to ensure the security and safety of the use of electronic map systems for ships planned to pass through the Gulfs of Suez and Aqaba, and the Suez Canal, as well as ships planned to enter Egyptian ports, to raise the level of maritime navigation safety and preserve the marine environment on the Egyptian coasts (Youssef et al., 2024).

This study adopts an interpretive approach, employing a survey questionnaire distributed to ECDIS trainees with shipboard experience using a quantitative method. The objective is to identify and discuss the various advantages and disadvantages of ECDIS standardization from the perspective of these trainees. Therefore, this paper covers the ECDIS standardization mechanism, introduces ECDIS training courses, summarizes previous research, and provides an overview of current training programs. It also details the research methodologies and materials used, presents the study findings and concludes with a discussion and recommendations.

The research problem highlights that since its inception, the IMO has been concerned with ensuring maritime safety in all its elements and with navigation safety. It has issued many decisions whose goal was to improve maritime safety and prevent maritime accidents. With the increase in many accidents, in which the human element was the most responsible in most cases, the importance of benefiting from the rapid development witnessed in electronic device technology has emerged to reduce the factors causing these accidents (Weintrit, 2019).

The core issue of this research is the lack of standardization in ECDIS interfaces, which leads to challenges in crew training, increased risk of human error, and inconsistencies in navigational safety practices. This research paper emphasizes the importance of deck officers regularly maintaining and enhancing their ECDIS knowledge and skills through ongoing or refresher training, ensuring efficient utilization as evidenced by navigational assessments, audits, and external inspections such as Port State Control (PSC) and Ship Inspection Report (SIRE) as they are two key elements related to maritime safety and the management of ECDIS. The study aims are to evaluate the effectiveness of implementing a standardized interface, known as S-Mode, for ECDIS to address the challenges caused by the current lack of standardization and to facilitate the adoption of the S-Mode by investigating factors influencing this adoption using various technology adoption models.

ECDIS STANDARDIZATION MODE

S-Mode can be described as a standardized user interface for ECDIS that offers a uniform display, menu structure, and operational settings across different systems to simplify training, reduce human error, and enhance navigational safety (Weintrit, 2010; Zalewski, 2019). The Nautical Institute (NI) has actively contributed to developing e-navigation, incorporating the S-Mode concept. This concept, aimed at boosting operational safety and facilitating efficient training through a uniform display, menu system, and input device, has been refined over years of member input. First introduced in Seaways in March 2007, S-Mode received significant industry support as some of shipping companies like Maersk and MSC have praised S-Mode for its practical benefits, including reduced crew training and reduced human error risk. Pilot organizations like the UK Maritime Pilots' Association also noted its efficiency (Hagen, 2017).

The International Safety Management (ISM) Code mandates that officers be familiar with their ship navigational equipment, including ECDIS, to ensure safe operations, the S-Mode may facilitate this by offering a standardized interface, reducing the time and complexity involved in familiarizing crew members with different ECDIS models (Behera et al., 2021). Pilots often face significant challenges in quickly adapting to various ECDIS models with different interfaces, especially during approaching and departures from ports, S-Mode can address this by providing a consistent interface that minimizes confusion and enhances safety during critical pilotage operations. Shore-based training facilities also struggle to decide which specific tools to purchase for optimal student instruction, often not reflecting the actual tools on ships. Ship managers have limited influence over the technology provided by ship owners but must ensure that every vessel has qualified officers. Training institutions typically lack the resources and space to invest in a wide range of equipment samples for instruction (MacKinnon et al., 2015).

Role of S-Mode in ECDIS and e-Navigation

The "S-Mode" feature should be standard on all future navigation systems, defaulting to a standard display when activated and fully configurable via a standard menu system. Standard functions will be included, such as altering range and using EBL/VRM and parallel indexing. S-Mode aims to offer high functionality and ensure that anyone skilled in using it can efficiently operate navigation systems on any vessel equipped with it (Weintrit, 2010). S-Mode allows pilots or mariners to quickly configure systems with their preferred settings, overlay customized display characteristics, or access specialized information by saving preferences on a storage device or within the system. The IMO has suggested incorporating S-Mode into the STCW Convention, requiring changes to existing training frameworks. This includes revising syllabi, creating simulation exercises, and developing examination criteria. Training institutions are expected to implement dedicated modules focusing on theoretical knowledge and practical application, ensuring officers are proficient in navigating with a standardized ECDIS interface. This approach aligns with global standards to enhance maritime safety and operational efficiency (IMO, 2019; Vidan et al., 2018).

The default range and size of data presentation on ECDIS should be carefully set, with "Range / Scale" recommended at 3Nm and corresponding radar equipment at 6Nm as per the IMO Performance Standards for INS's Appendix 6 for route monitoring and collision avoidance tasks (IMO, 2007). With appropriate display offset, these values ensure clear chart information for route monitoring at 3Nm and adequate anti-collision operations at 6Nm. However, for fast ships traveling over 20 knots, reaction times can drop below 10 minutes, potentially leading to misconceptions about the range setting. Many modern ECDIS systems allow user-selectable scales to be converted to range and vice versa, while others only change the scale (Kastrisios and Pilikou, 2017). The ECDIS chart display for route monitoring must have a compelling dimension of at least 270 mm by 270 mm, with the backup system chart presentation at 250 mm or 250 × 250 mm, as per IMO Resolution MSC.232(82) (IMO, 2006). The IHO specifies S52 requirements for ECDIS display panels, defining resolution as the lowest number of lines per millimeter (L) determined by $L=864/s$, where s is the smaller size of the chart display area. For instance, with s=270mm, the pixel size is 0.312mm. While smaller displays are allowed, most ECDIS installations use 19" or larger flat panels to meet IMO ECDIS performance and display resolution requirements (IMO, 2006; Zalewski, 2019).

Implications of Implementing S-Mode in ECDIS Systems

The new IHO ENC Product Specification S-101 (Guideline, 2018) aims to simplify determining data coverage for the 3Nm range. According to S-101, when the system viewing scale is below the minimum display scale, data within the Data Coverage feature is not displayed unless the SENC lacks a smaller-scale dataset, which will display the data at all more minor scales. An overscale indication must be shown when the viewing scale exceeds the highest display scale (Palikaris and Mavraeidopoulos, 2020). A message must also appear on the same screen as the chart whenever a dataset covering the ship position has a maximum display scale that is more incredible than the mariner's selected viewing scale (MSVS). Misunderstandings about ECDIS default settings, such as "Off Center, with an appropriate look ahead" and "Selected Sea area: Around own ship with appropriate offset," persist. S-Mode standards may use ambiguous terms rather than standardized ones like "appropriate" (Zalewski, 2019).

The stabilization of data display is a problematic default option in S-Mode. S-Mode rules present data as "sea" stabilized in radar and "ground" stabilized in ECDIS. This aligns with collision regulations, where sea stabilization is used for radar and ground stabilization for course monitoring on charts. However, users of existing INS systems, which often default to ground GNSS stability for ECDIS and radar, may find this confusing. This setup allows easy transmission of ARPA targets and radar footage to chart displays. Still, new default values necessitate caution when assessing AIS and ARPA vectors and their potential fusion in ECDIS (Zalewski, 2019). Another issue with S-Mode default settings is the look-ahead feature. The ECDIS look-ahead is set to "Look-ahead time 6 min," while the radar look-ahead reads "Off Center, with Appropriate Look-Ahead." The term "look ahead" can be misleading, as it denotes offset distance in one technology and predicted time in another. Modern ECDIS systems rarely use look-ahead terminology, opting for alternative functions instead, which could lead to further confusion (Rutkowski, 2018).

Several international standards and IMO instruments address system design and information display (IMO, 2006, 2007; Zalewski, 2019). The S-Mode rules were developed using these standards and Human-Centered Design (HCD) as foundations. While this approach is generally expected to yield positive outcomes, it can have negative implications if source standards are adopted uncritically. For instance, conflicts can arise among radar equipment, ECDIS, and INS functions within the S-Mode framework. Simulated tests before adopting new ship equipment will help determine if S-Mode recommendations significantly improve navigation safety. Some S-Mode instructions may conflict with established seafarer practices without such testing (Tomczak, 2012). User feedback testing is crucial to ensure compliance with the new Performance Standards for the Presentation of Navigation-Related Information on Shipborne Navigational Displays (IMO, 2019).

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

This section reviews the literature on critical variables and their relationships. Structural Equation Modeling (SEM) has been widely used to examine maritime solution adoption factors. Lu et al. (2007) found that perceived utility and security protection did not significantly impact the adoption of liner shipping solutions. In a 2023 study, Makizadeh et al. explored the influence of information desire on perceived usefulness in marine sports on Qeshm Island. Analyzing data from 300 participants using SPSS and AMOS revealed a positive link between information needs and perceived usefulness. Lu et al. (2007) also provided SEM guidelines focusing on service acceptability and safety in liner shipping, finding that security measures influence perceived usability, based on 85 valid responses from top Chinese export enterprises.

Yang et al. (2022) examined the effects of social interaction technology on job performance and anxiety in ocean freight forwarding, using SEM to identify seven constructs, ultimately showing a link between perceived security and usability. Tsai (2016) explored seafarers' attitudes toward ECDIS by surveying deck officers on 110 vessels, finding that perceived usefulness significantly impacts their attitude toward using the system, with 138 valid responses out of 440 surveys showing a positive trend. Handayani and Dewi (2019) examined the influence of perceived ease of use on attitudes towards the Seagull Training Lab for marine English, collecting data from 374 participants, including three teachers. The study highlighted mixed opinions among teachers and students. Hsu and HSU (2012) compared the impact of perceived ease of use on attitudes toward ECDIS between inexperienced maritime students and experienced shipmates, using a sample of 144 students. They found a significant link between ease of use and positive attitudes toward ECDIS in navigation. Pan et al. (2016) studied the design of a marine education information system for college students, revealing that ease of use and utility enhance learning when the system is simple and straightforward, thus positively affecting attitudes toward its usage.

A survey of 110 ships revealed that deck officers' positive attitudes toward ECDIS are strongly linked to their intention to use it, highlighting the system potential to enhance maritime safety (Tsai, 2016). Pan et al. (2016) explored how marine education information systems impact college students' learning, finding that more superficial and understandable systems improve learning outcomes. Their regression analysis demonstrated a 65.6% predictive capacity toward user attitudes, emphasizing the need to promote maritime safety. Studies by Antwi-Boampong et al. (2022) and Alharbi et al. (2022) examined factors influencing technology use, identifying social influence, performance expectations, effort expectations, and environmental conditions as key drivers. Their research, involving 374 participants from the marine and port industries, underscored the significance of these factors in shaping behavioral intentions toward technology use.

RESEARCH METHODS

Figure 1 outlines how various factors like Responsiveness, Security, Information Quality, Information Credibility, and Needs of Information influence the Perceived Usefulness and Perceived Ease of Use of the ECDIS S-Mode system. These perceptions shape the user's Attitude Toward Use, which affects their Behavioral Intention to use the system and ultimately determines the Actual Use of the system. The model helps understand what drives system adoption and user engagement.

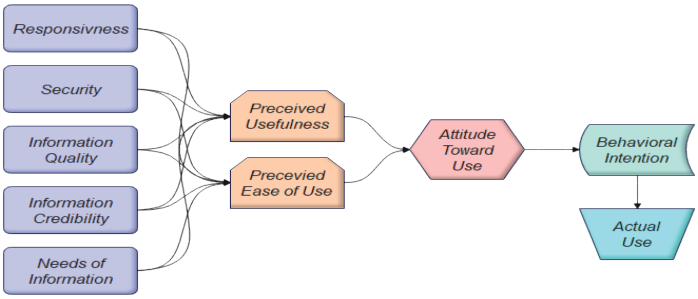

Figure 1 The Framework of ECDIS S-Mode Study

Based on this framework, these hypotheses are raised:

- ***H1: There is a significant relationship between Independent Variables and Perceived Usefulness***
- ***H2: There is a significant relationship between Independent Variables and Perceived Ease of Use***
- ***H3: There is a significant relationship between Perceived Usefulness, Perceived Ease of Use, and Attitude Toward Use***
- ***H4: There is a significant relationship between Attitude Toward Use and Behavioral Intention***
- ***H5: There is a significant relationship between Behavioral Intention and Actual Use***

Trainees from the Arab Academy for Science, Technology and Maritime Transport (AASTMT) who have a background in using ECDIS for ship navigation were involved in an extensive survey conducted during an ECDIS refresher course held in a simulator complex. Out of the 700 surveys that were given to the trainees, 425 of them were filled out completely by participants who chose to participate. However, eight surveys were not considered for analysis because they contained data leaving a total of 417 valid responses that were studied.

The evaluation focused on implementing "S Mode" in electronic navigation instruments, assessing various aspects based on established literature (Sek et al., 2010; Erkan and Evans, 2016; Rahman et al., 2017; Singh et al., 2020). This thorough examination seeks to enhance comprehension of ECDIS standardization and how it influences the efficiency and safety of navigation practices as a whole. Table 1 outlines the respondent demographics of the participants surveyed and showcases a range of ages represented in the data. The biggest age bracket is the 30- to 39-year-olds making up 27.1% of the group surveyed; next comes the 22 to 29 age group at 26.1% and the 50 to 59 age categories at 19.4%. The diverse age range allows for an examination of trends related to age and variations, in answers.

Regarding professional qualifications, 44.1% of the respondents hold a Chief Mate Certificate of Competency (CoC), indicating advanced expertise and specialized training. Additionally, 33.1% possess a Bachelor's degree and a 2nd Mate CoC, highlighting a solid foundation in maritime education. A significant 22.8% have obtained a Master's CoC, representing the group highest academic and professional qualification. This diverse educational background enhances the study robustness, providing a comprehensive perspective on the experiences and insights of deck officers regarding ECDIS standardization and its role in maritime operations.

Table 1: Descriptive Statistics of Respondents Profile

	Frequency	Percent	Total
Age			
22-Less than 30	109	26.1	417
30- Less than 40	113	27.1	
40- Less than 50	75	18.0	
50- Less than 60	81	19.4	
60 or older	39	9.4	
Education			
Bachelor's degree + 2nd Mate CoC	138	33.1	417
Chief Mate CoC	184	44.1	
Master CoC	95	22.8	

RESULTS AND FINDINGS

The study used structural equation modeling, or SEM, to evaluate the research hypotheses and interpret the data. The SEM was carried out using AMOS 24. First, a measurement model was created to verify the model that was being examined. The measurement model fit to the data was evaluated using confirmatory factor analysis (CFA). Next, the multicollinearity and normalcy hypotheses were verified. Lastly, descriptive analysis for research variables and participant profiles was given using SPSS version 25.

Data Testing Using Validity and Reliability

As shown in Table 2, validity and reliability tests are performed to assess the investigated data. Average Variance Extracted, or AVE, is a tool for evaluating convergent validity, where all AVE values are between 73.498% and 87.055%. This means that all AVE values are greater than 50%. In addition, the factor loadings are computed to reflect the convergent validity, where all loadings are shown to be between 0.724 and 0.878. This means that all loadings are more significant than 0.4, reflecting adequate validity for the constructs under study. Additionally, the Kaiser-Meyer-Olkin (KMO) values are calculated to assess the suitability of the sample. The sample is deemed sufficient for that construct if the appropriate KMO value for a given build is at least 0.5. All KMO values were between 0.500 and 0.975, showing an adequate sample under study.

Table 2: Validity and Reliability Test

Variables	KMO	AVE %	Cronbach's α	Items	Factor Loadings
Respon-siveness	.764	86.644	.923	RES1	.869
				RES2	.861
				RES3	.869
Security	.874	86.586	.948	SEC1	.854
				SEC2	.874
				SEC3	.865
				SEC4	.870
Information Quality	.760	85.386	.914	IQ1	.847
				IQ2	.856
				IQ3	.858
Information Credibility	.873	86.362	.947	IC1	.868
				IC2	.867
				IC3	.865
				IC4	.856
Needs of Information	.500	84.901	.822	NoI1	.849
				NoI2	.849
Perceived Usefulness	.971	76.884	.962	PU1	.773
				PU2	.751
				PU3	.784
				PU4	.774
				PU5	.755
				PU6	.765
				PU7	.770
				PU8	.774
				PU9	.774
Perceived Ease of Use	.947	73.498	.940	PEU1	.737
				PEU2	.768
				PEU3	.731
				PEU4	.725
				PEU5	.725
				PEU6	.724
				PEU7	.735
Attitude Toward Use	.975	81.822	.972	ATU1	.807
				ATU2	.833
				ATU3	.794
				ATU4	.820
				ATU5	.816
				ATU6	.823
				ATU7	.831
				ATU8	.813
				ATU9	.827
Behavioral Intention	.764	87.055	.926	BI1	.870
				BI2	.864
				BI3	.878
Actual Use	.758	85.530	.915	AU1	.840
				AU2	.860
				AU3	.866

Measurement Model using the Confirmatory Factor Analysis

The CFA is used to perform the measurement model, and the model fit indices indicate that the model fits the data well. This had been shown as the minimum discrepancy or chi-square divided by the degrees of freedom (CMIN/DF) was 1.075 (< 2.00); the Bentler-Bonett normed fit index (NFI) was 0.952 (> 0.90); goodness of fit (GFI) was 0.905 (> 0.90); the probability of getting as more considerable discrepancy as occurred with the present sample (p-value) was 0.000 (P-value < 0.05); adjusted goodness of fit index (AGFI) was 0.900 (> 0.90); and the Tucker-Lewis index (TLI) was 0.996 (> 0.95); the comparative fit index (CFI) was 0.996 (> 0.90). Also, the root means square residual (RMR) was 0.022 (< 0.1); the root mean square of approximation (RMSEA) was 0.013 (< 0.1). The factor loadings are displayed on arrows in Figure 2, which indicates good factor loadings for the CFA and depicts the implemented confirmatory analysis.

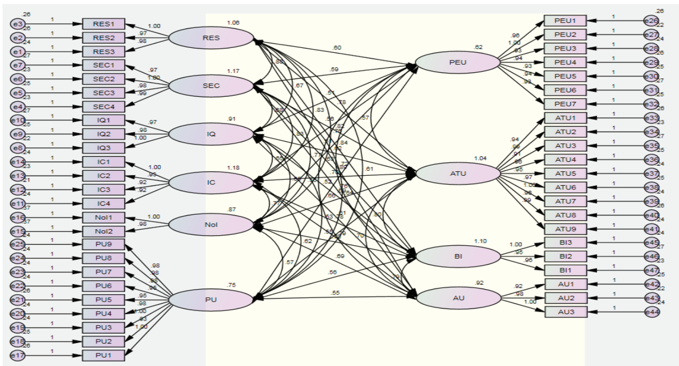

Figure 2: CFA for the Measurement Model

Table 3 presents the factor loadings of the statements allocated to each construct in the measurement model, displayed after the model fit indices for the study model are accepted. All factor loadings are determined to be within 0.904 and 1.00, and all P-values are below 0.05. This indicates that all factor loadings are higher than 0.4, indicating a valid model.

Table 3: Item Loading after Confirmatory Factor Analysis

			Estimate	SE.	CR.	P
RES3	<---	RES	.982	.036	27.252	***
RES2	<---	RES	.973	.036	26.719	***
RES1	<---	RES	1.000			
SEC4	<---	SEC	.985	.032	30.895	***
SEC3	<---	SEC	.980	.032	30.236	***
SEC2	<---	SEC	1.000			
SEC1	<---	SEC	.969	.033	29.354	***
IQ3	<---	IQ	1.000			
IQ2	<---	IQ	.976	.038	25.360	***
IQ1	<---	IQ	.974	.039	25.017	***
IC4	<---	IC	.915	.031	29.092	***
IC3	<---	IC	.921	.031	30.043	***
IC2	<---	IC	.932	.031	29.631	***
IC1	<---	IC	1.000			
NoI2	<---	NoI	.983	.052	19.061	***
NoI1	<---	NoI	1.000			
PU1	<---	PU	.999	.041	24.300	***
PU2	<---	PU	.926	.039	23.709	***
PU3	<---	PU	1.000			
PU4	<---	PU	.976	.040	24.588	***
PU5	<---	PU	.949	.040	23.734	***
PU6	<---	PU	.949	.039	24.122	***
PU7	<---	PU	.976	.040	24.529	***
PU8	<---	PU	.984	.040	24.561	***
PU9	<---	PU	.976	.040	24.500	***
PEU1	<---	PEU	.960	.044	21.988	***
PEU2	<---	PEU	1.000			
PEU3	<---	PEU	.928	.042	21.991	***
PEU4	<---	PEU	.941	.044	21.607	***
PEU5	<---	PEU	.931	.043	21.657	***
PEU6	<---	PEU	.937	.044	21.327	***
PEU7	<---	PEU	.935	.043	21.903	***
ATU1	<---	ATU	.943	.034	28.094	***
ATU2	<---	ATU	.988	.033	29.502	***
ATU3	<---	ATU	.911	.033	27.326	***
ATU4	<---	ATU	.962	.033	28.742	***
ATU5	<---	ATU	.951	.033	28.780	***
ATU6	<---	ATU	.974	.034	28.913	***
ATU7	<---	ATU	1.000			
ATU8	<---	ATU	.964	.034	28.321	***
ATU9	<---	ATU	.988	.034	29.206	***
AU1	<---	AU	.923	.037	24.931	***
AU2	<---	AU	.979	.037	26.426	***
AU3	<---	AU	1.000			
BI3	<---	BI	1.000			
BI2	<---	BI	.946	.035	27.268	***
BI1	<---	BI	.959	.034	28.393	***

DESCRIPTIVE ANALYSIS

In Table 4, the study variables descriptive analysis is displayed. Respondents generally gave these dimensions a positive rating. For instance, Responsiveness received a mean score of 3.1559, while Security and Information Quality averaged 3.1247 and 3.0935, respectively. Information Credibility was rated slightly lower with a mean of 3.0312, and Needs of Information had a mean of 2.9664. With a mean score of 3.3381, Perceived Usefulness was highly preferred, closely followed by Perceived Ease of Use at 3.5132. Attitude Toward Use, with a mean of 3.5060, and Behavioral Intention, with a mean of 3.5755, also reflect positive perceptions. Actual Use received the highest mean score at 3.6091. It is important to note that while these means suggest a positive outlook, the standard deviations for each variable vary, implying some level of variability in respondents' opinions, which could be further explored in subsequent analyses. These results collectively provide a robust foundation for understanding and improving various dimensions within the context of the study.

Table 4: Descriptive Analysis of the Research Variables

Variables	Mean	Std. Deviation	Frequency				
			1	2	3	4	5
Respon-siveness	3.1559	1.08848	30	94	109	149	35
Security	3.1247	1.14303	39	90	110	136	42
Information Quality	3.0935	1.05538	28	80	184	75	50
Information Credibility	3.0312	1.09697	32	101	153	84	47
Needs of Information	2.9664	1.07140	33	112	143	94	35
Perceived Usefulness	3.3381	1.06442	25	42	189	89	72

Perceived Ease of Use	3.5132	1.03564	13	59	119	153	73
Attitude Toward Use	3.5060	1.16874	15	88	84	131	99
Behavioral Intention	3.5755	1.15803	15	66	117	102	117
Actual Use	3.6091	1.12370	10	70	106	118	113

Normality Testing for the Research Variables

As shown in Table 5, the Kolmogorov-Smirnov test of normality was formally used to evaluate the normalcy assumption for the study variables. Given that the corresponding P-values are below 0.05, this suggests that the study variables are not regularly distributed. When a formal test suggests that the results are not normally distributed, an informal test is employed to evaluate near normality. The outcomes of a non-official normalcy test are shown in Table 5. If the results for kurtosis and skewness fall between ±1, the data are regarded as broadly usual.

Table 5: Testing of Normality

	Kolmogorov-Smirnov[a]			Skewness	Kurtosis
	Statistic	Df	Sig.		
Responsive-ness	.222	417	.000	-.257	-.769
Security	.205	417	.000	-.217	-.824
Information Quality	.236	417	.000	.084	-.342
Information Credibility	.197	417	.000	.103	-.598
Needs of Information	.178	417	.000	.091	-.621
Perceived Usefulness	.239	417	.000	-.143	-.266
Perceived Ease of Use	.223	417	.000	-.368	-.474
Attitude Toward Use	.215	417	.000	-.305	-.995
Behavioral Intention	.171	417	.000	-.297	-.900
Actual Use	.190	417	.000	-.310	-.922

Testing Multicollinearity

Multicollinearity is detected using the Variance Inflation Factor (VIF), which also displays the level of correlation between the study variables. Table 6 VIF values are all less than 5, indicating that multicollinearity between the independent variables is not a problem.

Table 6: VIF Values for Independent Variables

Independent Variables	VIF
Responsiveness	3.409
Security	3.080
Information Quality	2.003
Information Credibility	2.246
Needs of Information	2.770

Testing the Research Hypotheses

The findings from the analysis of the relationship between independent and dependent variables are shown in this section. The resultant correlation matrix is shown in Table 7, and it can be shown that Responsiveness, Security, Information Quality, Information Credibility, Information Needs, and Perceived Usefulness have a significant positive association (P-value 0.05; r > 0). Additionally, there is a substantial positive link (P-value 0.05; r > 0) between Responsiveness, Security, Information Quality, Credibility, Information Needs, and Perceived Ease of Use. Additionally, a strong positive correlation exists between Attitude toward Use and Perceived Usefulness, Perceived Ease of uUe, and Perceived Usefulness (P-value 0.05; r > 0).

Furthermore, Behavioral Intention and Attitude Toward Usageage have a solid favorable correlation (P-value 0.05; r > 0). Additionally, Actual Use and Behavioral Intention have a strong positive association (P-value 0.05; r > 0).

Table 7: Correlation Matrix for the Research Variables

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Responsiveness	r	1									
	P-value										
	N	417									
2. Security	r	.788**	1								
	P-value	.000									
	N	417	417								
3. Information Quality	r	.651**	.618**	1							
	P-value	.000	.000								
	N	417	417	417							
4. Information Credibility	r	.678**	.666**	.554**	1						
	P-value	.000	.000	.000							
	N	417	417	417	417						
5. Needs of Information	r	.726**	.702**	.649**	.680**	1					
	P-value	.000	.000	.000	.000						
	N	417	417	417	417	417					
6. Perceived Usefulness	r	.743**	.714**	.652**	.672**	.693**	1				
	P-value	.000	.000	.000	.000	.000					
	N	417	417	417	417	417	417				
7. Perceived Ease of Use	r	.795**	.764**	.702**	.680**	.724**	.743**	1			
	P-value	.000	.000	.000	.000	.000	.000				
	N	417	417	417	417	417	417	417			
8. Attitude Toward Use	r	.773**	.786**	.653**	.648**	.697**	.666**	.802**	1		
	P-value	.000	.000	.000	.000	.000	.000	.000			
	N	417	417	417	417	417	417	417	417		
9. Behavioral Intention	r	.758**	.763**	.634**	.620**	.645**	.620**	.835**	.809**	1	
	P-value	.000	.000	.000	.000	.000	.000	.000	.000		
	N	417	417	417	417	417	417	417	417	417	
10. Actual Use	r	.738**	.732**	.651**	.698**	.740**	.659**	.809**	.797**	.800**	1
	P-value	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	417	417	417	417	417	417	417	417	417	417

**. Correlation is significant at the 0.01 level (2-tailed).

The influence of the research factors is shown by the SEM analysis in Table 8. That is what might be seen:

In support with the first premise: Responsiveness was found to have a sizable beneficial impact (Estimate = 0.128 > 0; P-value = 0.049 < 0.05), Security (Estimate = 0.138 > 0; P-value = 0.012 < 0.05), Information Quality (Estimate = 0.157 > 0; P-value = 0.003 < 0.05), Information Credibility (Estimate = 0.123 > 0; P-value = 0.015 < 0.05), and Needs of Information (Estimate = 0.206 > 0; P-value = 0.019 < 0.05) on Perceived Usefulness. Moreover, the dependent variable variation in perceived usefulness is about 59.9%, as explained by the independent variables, according to the R-squared value of 0.599. From the results, it was found that the need for information (0.206) is the most critical factor that affects perceived usefulness, followed by information quality (0.157), security (0.138), responsiveness (0.128), and information credibility (0.123), respectively.

The second hypothesis: Observation revealed that there is a notable benefit of Responsiveness (Estimate = 0.245 > 0; P-value = 0.000 < 0.05), Security (Estimate = 0.110 > 0; P-value = 0.022 < 0.05), and Information Quality (Estimate = 0.189 > 0; P-value = 0.000 < 0.05) on Perceived Ease of Use, while, there is an insignificant effect of Information Credibility (P-value = 0.145 > 0.05), and Needs of Information (P-value = 0.162 > 0.05) on Perceived Ease of Use. Furthermore, the dependent variable's Perceived Ease of Use R-squared value of 0.658 suggests that the independent factors account for around 65.8% of the variation in the dependent variable. According to outcomes, it was found that Responsiveness (0.245) is the most crucial factor that affects Perceived Ease of Use, followed by Information Quality (0.189), Security (0.110), Needs of Information (0.106), and Information Credibility (0.064), respectively.

The third hypothesis: It is evident that there is a noteworthy benefit between Perceived Usefulness (Estimate = 0.244 > 0; P-value = 0.000 < 0.05) and Perceived Ease of Use (Estimate = 0.762 > 0; P-value = 0.000 < 0.05) on Attitude Toward Use. Additionally, the dependent variable's Attitude Toward Use R-squared value of 0.556 suggests that the independent factors account for around 55.6% of the variation in the dependent variable.

The fourth hypothesis noted a notable benefit to Attitude Toward Use on Behavioral Intention (Estimate = 0.792 > 0; P-value = 0.000 < 0.05). Additionally, the dependent variable, Behavioral Intention, may be explained by Attitude Toward Use to the tune of about 59.8% based on the R-squared value of 0.598.

The fifth hypothesis: The Behavioral Intention was found to have a noteworthy favorable impact on aAtual Use (Estimate = 0.742 > 0; P-value = 0.000 < 0.05). Furthermore, based on the R-squared value of 0.640, the dependent variable, Actual Use, may explain approximately 64% of the variation in the dependent variable.

Table 8: SEM Analysis for the Research Variables

1			Estimate	P	R^2
Perceived Usefulness	<---	Respon-siveness	.128	.049	
Perceived Usefulness	<---	Security	.138	.012	
Perceived Usefulness	<---	Information Quality	.157	.003	.599
Perceived Usefulness	<---	Information Credibility	.123	.015	
Perceived Usefulness	<---	Needs of Information	.206	.019	
Perceived Ease of Use	<---	Respon-siveness	.245	***	
Perceived Ease of Use	<---	Security	.110	.022	
Perceived Ease of Use	<---	Information Quality	.189	***	.658
Perceived Ease of Use	<---	Information Credibility	.064	.145	
Perceived Ease of Use	<---	Needs of Information	.106	.162	
Attitude Toward Use	<---	Perceived Usefulness	.244	***	.556
Attitude Toward Use	<---	Perceived Ease of Use	.762	***	
Behavioral Intention	<---	Attitude Toward Use	.792	***	.598
Actual Use	<---	Behavioral Intention	.742	***	.640

AGFI = 0.861, CFI = 0.975, CMIN/DF = 1.510, GFI = 0.875, and RMSEA = 0.035 are all within acceptable ranges for the model fit indices. The SEM model used to analyze the impact of the research model is depicted in Figure 3.

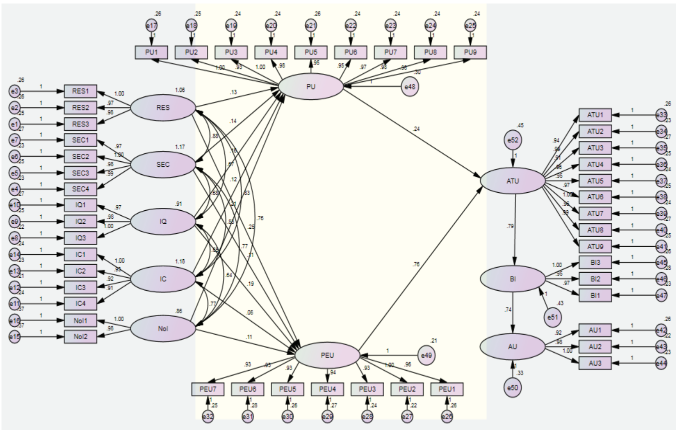

Figure 3: SEM for the Research Variables

DISCUSSION AND CONCLUSION

The goal of these increasingly demanding technical specifications over the last two decades has been to meet IMO performance requirements while granting numerous manufacturers the autonomy to decide on the equipment capabilities, software menu structures, interfaces, behavior, and other features. Different system design components began to exhibit variations in ECDIS models, prompting industry associations like the Nautical Institute to explore standardization. Performance requirements are inadequate to form the foundation of a functional and user-friendly system design because of this tendency. Users expected to switch between systems cannot afford the intensive user training necessary to run each system efficiently. According to the first hypothesis, Responsiveness, Information Quality, and Information Needs significantly improve perceived usefulness. These outcomes align with the findings of some investigations such as those of Lin and Kim, (2016) and Al-Eqab and Adel (2013). However, these outcomes conflict with the findings of some investigations such as Kang and Namkung (2019 and Filieri et al. (2021), which may be attributed to differences in user context and the evolving landscape of ECDIS technology, suggesting that older research may not fully capture recent technological advancements or the heightened emphasis on user-centric designs specific to maritime needs.

Regarding the second hypothesis, although information requirements and credibility minimally affect Perceived Ease of Use, Responsiveness and Information Quality have significant positive impacts, consistent with findings by Jo and Park (2023) and Mazur and Nowakowski (2017). In contrast, Khalilzadeh et al. (2017) and Hansen et al. (2018) report differing results, likely due to their focus on broader technology adoption frameworks that do not account for the specific operational pressures of maritime navigation. This discrepancy highlights how sector-specific nuances, such as the immediate need for reliable and intuitive interfaces in critical navigation scenarios, can shape user perceptions differently than in general technology contexts.

The third hypothesis demonstrates that Perceived Utility and Ease of uUe greatly enhance attitudes toward usage, aligning with studies by Suki and Suki (2011), Elkaseh et al. (2016), and Abdullah et al. (2016). These findings underscore the importance of intuitive design and practical utility in maritime settings, where user familiarity with navigation systems directly impact safety and operational efficiency. The divergence from other research may stem from differing levels of user experience and the dynamic nature of technological updates, which are more pronounced in the specialized field of maritime ECDIS usage.

For the fourth hypothesis, the strong positive impact of Attitude Toward Use on Behavioral Intention is consistent with findings by Yeo et al. (2017) and Salim et al. (2019). Still, it contrasts with some studies like Ramprakash (2016) and Alharbi et al. (2022). This difference could be attributed to variations in the user population. Maritime officers often face higher stakes in system adoption decisions due to the direct link between navigation technology and safety, unlike users in less safety-critical environments. Similarly, the fifth hypothesis reveals that behavioral intention favorably impacts actual use, aligning with studies by Park et al. (2012) and Alharbi et al. (2022). The discrepancy with earlier research can be linked to the evolving training environments and regulatory pressures unique to the maritime industry, which continually shape user behavior in ways not captured by broader, less specialized studies.

In conclusion, each training method has its strengths and challenges. The maritime context necessitates a balance between intuitive system design and thorough training due to the expanding number of ships without traditional navigation tools and the increasing diversity of ECDIS models. The findings emphasize that relying solely on the individual commitment of officers is insufficient. Introducing minimum standards for specific training is crucial to ensure officers have the necessary skills, familiarity, and confidence to operate various ECDIS models effectively, recognizing unique system features and responding to specific settings and indications.

A limitation of this paper is the potentially restricted generalizability due to the sample size of 417, which may not represent diverse ECDIS users and overlook regional and cultural differences. This could affect the applicability of the findings across different contexts. Additionally, reliance on self-reported data introduces biases such as social desirability bias. Future research should use a larger, more diverse sample to improve accuracy and complement self-reports with observational studies and interviews.

RECOMMENDATIONS

- Prioritize S-Mode adoption on high-risk vessels, like tankers and passenger ships in congested waterways. This will reduce navigational errors and enhance safety in critical maritime zones.

- Develop tiered ECDIS training based on user experience, incorporating scenario-based exercises for advanced users. This ensures all officers are well-prepared for real-world challenges, minimizing accidents.

- Establish industry-wide interface design guidelines to standardize critical ECDIS functions across manufacturers. This reduces familiarization time and human error, allowing seamless skill transfer between different systems.

- Mandate routine software updates and enhanced cybersecurity measures for ECDIS systems to protect against cyber threats and ensure reliable operation.

- Foster collaboration between maritime

academies and ship operators to create training programs with real-world simulations, ensuring that training is directly relevant to actual ship operations, thereby improving maritime safety.

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