The Role of ECDIS in Improving Situation Awareness

Ender Asyali
Assoc. Prof. Dr. Master Mariner, Dokuz Eylul University,
ender.asyali@deu.deu.tr

Abstract: Efficient and safe navigation requires the systematic management of numerous socio-technical system components such as personnel, information, procedures, equipment and facilities. Electronic navigational systems are becoming a focal sub-system for appraisal, planning, execution and monitoring steps of safe and efficient navigation. As a result of high level integration and interaction between navigation components on a unique ECDIS display, the quantity and complexity of data and information available to the Officer of Watch (OOW) is dramatically increased. An important part of an OOW's job is developing Situation Awareness (SA) and keeping it up to date in a rapidly changing dynamic environment and ECDIS can play an important role in improving and maintaining SA of the OOW and the whole bridge team. The aim of this study is determine the relation between ECDIS and SA as it is perceived by the maritime officers. A questionnaire was applied to officers and masters to determine the reliability of existing ECDIS technology, the impact of the introduction of ECDIS on preventing collisions and groundings and the navigational skills of the OOW and SA from the users' perspective. 82.5 % of the respondents agreed and strongly agreed that "ECDIS improves SA of the OOW". The results show positive correlations between the role of ECDIS on improving SA and the effect of ECDIS on prevention of collisions and groundings as it perceived by the maritime officers. It is also concluded that respondents are generally favorable towards the introduction of ECDIS but there are still some objections related to the reliability and complexity of the systems and readiness of the operators.
Keywords: ECDIS, Situation Awareness, Cognitive Hierarchy

1. Introduction

Efficient and safe navigation requires the systematic management of numerous socio-technical system components such as personnel, information, procedures, equipment, and facilities. Although many navigational equipment and aids have been introduced, safety of navigation highly depends on the competence of masters and mates and their ability to make the right decision at the right time. "Acquiring relevant data and information from different sources, processing them, creating an accurate mental picture/model for accurate and timely decisions which allows safe action", is the process that makes a voyage safe or unsafe. Modern electronic navigational systems are becoming a focal sub-system for appraisal, planning, execution and monitoring steps of efficient and safe navigation and provide substantial data and information to the officers during this process.

The amendments to SOLAS Chapter V, Regulation 19, Section 2.4 "Carriage Requirements for Shipborne Navigational Systems and Equipment" which came into effect on 1 January 2011 state that "All ships irrespective of size shall have: nautical charts and nautical publications to plan and display the ship's route for the intended voyage and to plot and monitor positions throughout the voyage. An electronic chart display and information system (ECDIS) is also accepted as meeting the chart carriage requirements of this subparagraph". This amendment to SOLAS is governing the statutory introduction of ECDIS and will require all merchant vessels to be equipped with ECDIS by 2018.

"Electronic Chart Display and Information System (ECDIS) is a navigation information system, complying with the up-to-date chart requirements by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation-related information" [1]. ECDIS is not only an e-navigation tool which replaces paper charts and is a step towards a "paperless" bridge, but will also totally change the way/method of performing marine navigation. In the future this unique display will be the focal and main hub for Integrated Bridge Systems where all the voyage related data and information from different sources such as propulsion, navigation control systems, steering systems, alarms etc. can be reached, seen and used as a "decision support system" for routine and emergency situations.

The results of a Formal Safety Assessment of Electronic Chart Display and Information System study performed by Det Norske Veritas concluded that the main benefits of using ECDIS considered include:

- Liberate time for the navigators to focus on navigational tasks,
- Improved visual representation of fairway,
- More efficient updating of charts [2].

Studies related to the effectiveness of ECDIS concluded that the grounding frequency reductions achievable from implementing ECDIS vary between 11% and 38% for the selected routes [3]. Another study concluded that, by implementation of ECDIS the reduction in number of groundings and grounding related fatalities is calculated to be about 36%. Use of ECDIS is also expected to have a risk-reducing effect on collision scenarios. This effect was estimated to be 3%, mainly due to liberation of time to focus on monitoring of the traffic picture [4], [5]. Other research concluded that "ECDIS produced better performance and a smaller workload than paper charts and the radar overlay was slightly better than the separate radar display [6].

After the first introduction of marine radar on board of merchant vessels, ECDIS is the second important cornerstone for marine navigation which will provide real time position on electronic navigational charts (ENC). The collision of Stockholm and Andrea Doria on 25 July 1956 in heavy fog was written to maritime history as the first "Radar assisted collision" [7]. This term is summarizing the cause of accidents inherent in trusting and over relying to modern electronic aids and tools which are there for improving safety. Reason [8] defines this as trading off added protection for improved production and concludes that "Protective gains are frequently converted into productive advantages, leaving the organization with the same inadequate protection that prevailed before the event or with something even worse". He gave examples such as the Davy lamp in mining and radar assisted collisions in the maritime domain. Besides its numerous benefits, because of the high level of integration and complexity, ECDIS can also become an aid to accidents. "ECDIS-assisted accidents" may be a common term used to point out the role of ECDIS in maritime accidents. There are some early warnings of this type of accident such as the groundings of CFL Performer [9], CSL Thames [10] and MV Maersk Kendal [11].

Kopacz et al. present the process of maritime navigation as a kind of logical structure of functions and information and they defined that the ship's navigational information describes the whole environment of maritime navigation, including (a) geographical environment, (b) maritime navigation safety system,(c) own ship and (d) surrounding shipping traffic. The ship's navigational information should be adequate, comprehensive, timely acquired, updated, and easy to gather, store, retrieve and display in the most suitable form for use in the navigation process [12].

2. Situation Awareness

The term SA has been widely used in the aviation domain and it is being widely used in other high risk, complex and dynamic working environments where a huge amount of data and information is processed by the operator to make accurate, safe, effective and timely actions. As in many high risk jobs, developing and maintaining a high level of situation awareness is the most critical and challenging task in maritime watchkeeping. During watchkeeping, OOWs gather huge amounts of data and information from different sources (aids to navigation, other team members, other vessels, VTS etc.). By bringing these data and information together, they create an integrated "whole" which we call a "Mental Picture or Model" on which his/her decisions and actions will based. To have safe actions, creating accurate, timely and close to the real life mental picture in a rapidly changing environment is vital. During watchkeeping an OOW performs three important tasks such as collision avoidance, navigation and other administrative duties. For performing each of these tasks, a high level of SA is required.

An important part of an OOW's job is developing Situation Awareness (SA) and keeping it up to date in a rapidly changing and complex environment especially in coastal areas, congested waters, in ports and approaches. Studies indicate that SA is a significant causal factor in 88% of aviation accidents in which human error was indicated [13]. Other studies have found SA errors account for over 50% of air traffic control operational errors [14]. In the maritime domain, accident investigation results show that loss of SA has been directly responsible for the 27% of marine accidents [15]. U.S. Coast Guard analysis of navigational mishaps for cutters and boats revealed that 40% were due to a loss of situational awareness [16].

According to a synthesis of 15 SA definitions, Dominquez [17] defined SA as an "individual's continuous extraction of environmental information, and integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing future perception and anticipating future events". SA can also be defined as an internalized mental model of the current state of the operator's environment [18].

According to Endsley, SA is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [19]. SA is comprised of three levels: (1) perception: perceiving critical factors in the environment, (2) comprehension: understanding what those factors signify, and (3) projection: anticipating what will happen with the situation in the near future [20]. These levels are cumulative, as projection cannot occur without comprehension and comprehension cannot occur without perception.

Developing and maintaining SA can be a difficult process influenced by individual (e.g. experience, training, workload, etc), task (e.g. complexity) and systemic factors (e.g. interface design) and environment (visibility, darkness etc). The difficulty occurs from the interaction between the features of human information processing capabilities of operators and the design of the technologies. These difficulties have been labeled "SA Demons" where data overload is the foremost among these [21]. (See Table 1)

Table 1 Categories of SA demons

SA demons	Description
Attentional narrowing	As humans easily fall prey to attentional narrowing, systems need to support multitasking across multiple goals and decisions.
Requisite memory trap	Systems should not require operators to hold information in memory, since short term memory is limited and easily disrupted.
Workload, fatigue and other stressors	These factors all act to reduce already limited working memory and disrupt information acquisition.
Data overload	The volume and rate of change of data in many systems can outpace operators' abilities to keep up with it
Misplaced salience	The overuse of prominent visual features such as bright colors and flashing lights overwhelm and misdirect operators' attention.
Complexity creep	The more complex the system, the harder it is for operators to develop accurate situation comprehension and projection.
Errant mental models	Without good mental models of how a system operates being triggered, it is easy to misinterpret data based on how a different part of the system works.
Out-of-the-loop syndrome	Highly automated systems can leave operators with low awareness of the state of the system.

Source: Endsley et all [20]

2.1 Relationship between Cognitive Hierarchy and Situation Awareness

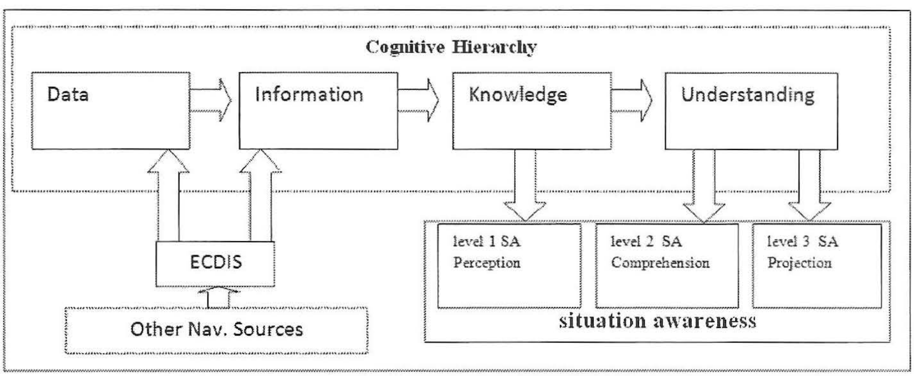
For understanding SA, the difference between the terms data, information, knowledge and understanding has to be defined. According to IAIDQ, *Data* is 1) symbols, numbers or other representation of facts; 2) the raw material from which information is produced when it is put in a context that gives it meaning. *Information* is 1) Data in context, i.e., the meaning given to data or the interpretation of data based on its context; 2) the finished product as a result of processing, presentation and interpretation of data [21]. Information is the data that have been shaped into a form that is meaningful and useful to human beings [22]. *Knowledge* is the understanding of the significance of information or information that is actionable. Knowledge contributes to *understanding* when experience, expertise and intuition are applied. The Cognitive Hierarchy Diagram (Figure 1) is describing this relationship.

The need to process and understand large volumes of data is critical to many endeavors, from the cockpit to military missions, from power plants to automobiles, and from space stations to day-to-day business operations[23]. Success (and even survival) depends on rapidly sorting through, understanding and assimilating vast quantities of data [24]. Bolia et al., [25] point out that increased availability of information does not necessarily mean that users will make better decisions and factors such as information overload, poor interpretation and the presence of non-relevant information and false data are likely to degrade rather than enhance SA.

Endsley and Jones [26] suggest that the way in which information is presented by such systems influences SA by determining how much information can be acquired, how accurately it can be acquired and to what degree it is compatible with SA needs. Endsley and Jones draw a parallel between Endsley's three levels of SA and the "cognitive hierarchy" of data, information, knowledge and understanding. Data correlated becomes information. Information converted into situational awareness becomes knowledge. Knowledge used to predict the consequences of actions leads to understanding. Endsley and Jones suggest that "knowledge" in this description equates to level 1 (Perception) SA and "understanding" equates to levels 2 (Comprehension) and 3 (Projection) SA. (See Fig. 1)

For reaching higher levels of SA, relevant, accurate and timely data and information which will be transformed to knowledge and understanding is required as it is mentioned at cognitive hierarchy.

Fig. 1 Relationship between ECDIS cognitive hierarchy and situation awareness



Source: Author, developed from [26]

Acquiring needed information and the way of presenting it can have a high impact on SA. Both lack of information and too much information can create problems with SA [27].

2.2 ECDIS and SA

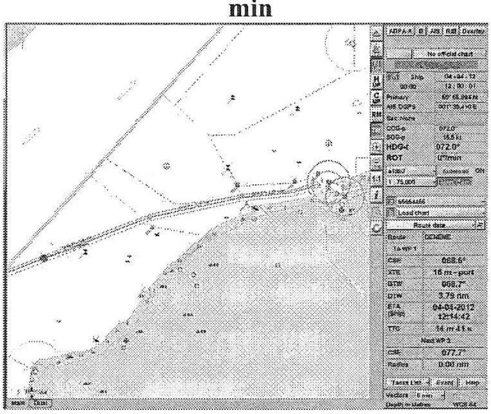
In the aviation domain, accidents investigations show that 75% of the SA errors were attributed to problems with level 1 SA including: data is not available, difficult to detect data, failure to monitor data, misperception of data and memory loss [23]. ECDIS related errors can be classified into two groups; 1) errors in displayed data associated with chart datum, shifting buoys, inaccurate hydrographic data, sensor limitations, poor resolution, user set-up errors, incorrect system configuration or calibration, system or sensor malfunction; 2) errors of interpretation by the operator [28]. Both of them have an impact on the SA of the operator.

Proper configuration of ECDIS layers is very important to SA. The OOW should have relevant, accurate and timely information to have and maintain a higher level of SA and should know what he can see and what he cannot see on ECDIS display. There should be clear watch hand-over procedures for officers in order to clarify the data and information available to them. Below, as an example, you may find three presentation options; min, medium and max. In the min. presentation mode, display mode is standard, radar overlay is off, safety contour is set to 0 meters and safety depth is 0 meter. As many of the important and critical data are not visible on the display at this level of presentation, it is difficult for the OOW to reach a high level of SA such as comprehension and projection as data is not available for level 1 SA. On the other hand in the max presentation mode, too much data from different sources can cause information overload limiting the perception of the OOW. The medium level presentation mode supports SA as it provides optimum levels of data on the display. (See Table 2)

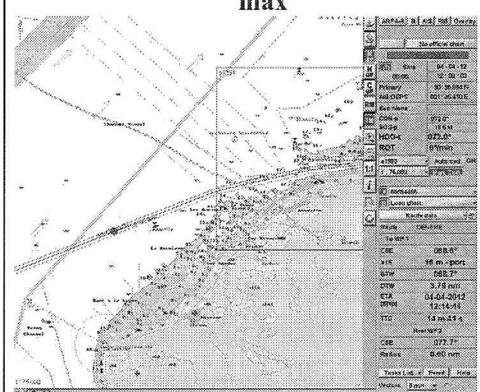
Table 2 Role of proper configuration of ECDIS layers on SA

Presentation mode	min	medium	max
scale	1/75.000	1/75.000	1/75.000
Display mode	Standard	Customized (sc:on)	All
Radar overlay	off	off	on
Safety contour	0m	10m	10m
Safety depth	0m	15m	15m

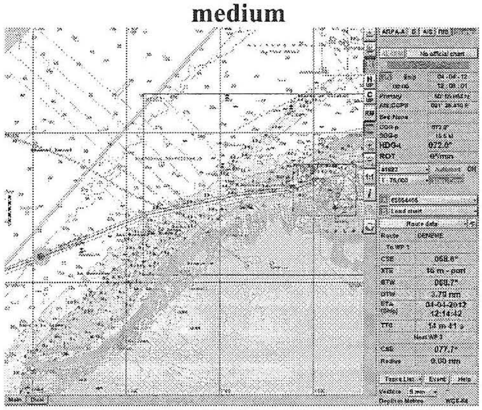
min



max



medium



Extract from Transas Navi-Sailor 3000 ECDIS-i

3. Research Design and Methodology

3.1 Objectives of the study

The aim of this study is to determine the attitudes of masters and mates towards ECDIS with a special focus on the relation between ECDIS and SA. A comparative analysis was performed by using quantitative technique among junior and senior officers to determine the reliability of existing ECDIS technology, the impact of introduction of ECDIS on preventing collisions and groundings, the navigational skills of the OOW and SA from the users' perspective.

3.2 Data Collection and Sampling

A one page questionnaire was used for collecting the data. Questions concerning the objectives of the study were developed in order to determine the attitudes of masters and mates towards ECDIS and to explore the relation between ECDIS and SA as it is perceived by the maritime officers. The questionnaire has three parts. The first part, which has two statements, is to determine the effect of ECDIS on preventing collisions and groundings. A 5-point "Likert Scale" with anchors at 1 (very low) and 5 (very high) was developed. For the second part, which has seven statements, a 5-point "Likert Scale" with anchors at 1 (I strongly do not agree) and 5 (I strongly agree) was developed to determine the attitudes of the officers concerning the introduction of ECDIS. The third part was an open ended question that allowed respondents to write their thoughts, in their own words, about the introduction of ECDIS. Nominal scales were used to collect data about the profile of the employees.

Convenience sampling method, which is a non probability sampling technique that attempts to obtain a sample of convenient elements, was chosen as the sampling technique [29]. The study was performed with Turkish Officers and Masters having an unlimited license and who had attended a two day ECDIS course training at DEU Maritime Faculty between June 2008 and October 2011. The questionnaire was applied at the end of the course and 230 usable questionnaires were collected. Data processing was maintained by SPSS (Statistical Package for the Social Sciences) Program.

4. Findings

4.1 Profile of the Respondents

Table 3. Summarizes the profile of the respondents. 42.2% (n: 95) of the respondents were oceangoing deck officers, 27.1% (n: 61) oceangoing chief officers and 30.7% (n: 69) were oceangoing masters. The average sea experience of the respondents is 7 years (Std. Dev. 7.2) which is 1 year min and 33 years for maximum. 47.0% (N: 108) of the respondents had experience on board with ECDIS. But care should be taken that the experience was not always on ECDIS complying with IMO performance standards.

Table 3 Profile of the respondents

Sea experience	n	%	License	n	%	Experience with ECDIS	n	%
1-3 years	93	41.7	Deck Officer	95	42.2	Yes	108	47.0
4-9 years	79	35.4	Chief Officer	61	27.1	No	116	50.4
10+ years	51	22.9	Master	69	30.7	Missing	6	2.6
Total	223	100.0	Total	225	100.0	Total	230	100.0

4.2 Perception of Officers Concerning the Introduction of ECDIS

Overall mean scores and standard deviations are listed in terms of overall mean score and standard deviation in Table 4. In the first part of the questionnaire, "The effect of ECDIS on prevention of groundings' (μ=4.1071), is found higher than "The effect of ECDIS on prevention of collisions" (μ=3. 84). In the second part of the questionnaire, "ECDIS is an aid to navigation that improves safety" (μ=4.43), "ECDIS improves SA of OOW" (μ=4.20) were determined as the statements having the highest mean scores. 82.5% (n: 189) of the respondents are agree (38.4) and strongly agree (44.1) that "ECDIS improves SA of OOW'. "ECDIS has negative contributions to the safety of navigation" (μ= 2.25) and "Usage of ECDIS reduces the navigational skills of officers" (μ= 3.03) were determined as the statements having lowest mean scores. (See Table 5)

Table 4 Perception of officers concerning the role of ECDIS on preventing collisions and groundings

STATEMENTS	n	Mean Score	Std. Dev.
The effect of ECDIS on prevention of collisions	227	3.84	1.213
The effect of ECDIS on prevention of groundings	226	4.65	.658

Note: 1= very low; 5=very high

Table 5 Perception of officers concerning ECDIS

STATEMENTS	n	Mean Score	Std. Dev.
ECDIS improves SA of OOW	229	4.20	.913
ECDIS has negative contributions to the safety of navigation	228	2.25	1.355
I prefer to have paper charts with ECDIS on board	230	3.49	1.546
The existing technology is relevant for the safe usage of ECDIS	227	3.42	1.243
ECDIS is an aid to navigation that improves safety	225	4.43	.894

STATEMENTS	n	Mean Score	Std. Dev.
The usage of ECDIS reduces the navigational skills of officers	230	3.03	1.483
Usage of ECDIS with radar overlay function enhance safety of navigation	228	3.83	1.300

Note: 1= I strongly disagree; 5=I strongly agree

In addition to the descriptive statistics, hypotheses tests (t-test and Analysis of Variance) were conducted in order to find the significant differences with regard to the specific variables such as participants' license, sea experience and their experience on board with ECDIS.

H1: Attitude of officers towards ECDIS differs according to their license. Analysis of variance (ANOVA) test showed the most significant difference for the statements are "I prefer to have paper charts with ECDIS on board" (F = 6.268; *p*-value = 0.002) and "The usage of ECDIS reduces the navigational skills of officers" (F = 5.928; *p*-value = 0.003) with respect to their license (master, chief officer and deck officers).

H2: Attitude of officers towards ECDIS differs according to their sea experience. Analysis of variance (ANOVA) test showed that there is not any significant difference for the statements of with respect to sea experience.

H3: Attitude of officers towards ECDIS differs according their experience on board of vessels with ECDIS.
"I prefer to have paper charts with ECDIS on board." with *p*-value of 0.022 (t value = 2.311) and "The existing technology is relevant for the safe usage of ECDIS." with *p*-value of 0.022 (t value = 2.826.) appear to differ significantly with respect to whether they have experience on board of vessels with ECDIS or not.

The data shows positive moderate correlations between "ECDIS improves SA of OOW" and "the effect of ECDIS on prevention of collisions" ($r=.391$, $p<0.01$); "the effect of ECDIS on prevention of groundings" ($r=.388$, $p<0.01$). This correlation concludes that ECDIS plays a significant role in prevention of collisions and groundings by improving SA.

The data shows positive moderate correlations between "the existing technology is relevant for the safe usage of ECDIS" and "the effect of ECDIS on prevention of collisions" ($r=.238$, $p<0.01$). Also there is a positive moderate correlation between "ECDIS is an aid to navigation that improves safety" and "the effect of ECDIS on prevention of collisions" ($r= 0.247^{**}$, $p<0.01$); "the effect of ECDIS on prevention of groundings" ($r=.401$, $p<0.01$). (See Table 6)

Table 6 Correlation matrix for statements

Statements	the effect of ECDIS on prevention of collisions	the effect of ECDIS on prevention of groundings
ECDIS improves SA of OOW	.391**	.388**
ECDIS has negative contributions to the safety of navigation.	-.014	-.078
I prefer to have paper charts with ECDIS on board.	-.052	-.056
Existing technology is relevant for the safe usage of ECDIS.	.238**	.135*
ECDIS is an aid to navigation that improves safety	.247**	.401**
Usage of ECDIS reduces the navigational skills of officers	.037	-.048
Usage of ECDIS with radar overlay function enhances safety of navigation.	.176**	.062

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

4.3 Analysis of the Remarks of Participants

Sixty-nine respondents added their remarks to the survey. The attitude of respondents towards ECDIS is clustered into three categories as favorable (21 respondents), conditionally favorable (40 respondents) and unfavorable (8 respondents).

The impact of ECDIS on mitigating workload, easing chart correction and voyage planning, supporting decision making, and supporting OOW make attitude of the respondents favorable to the ECDIS. Also it is mentioned that ECDIS is an important navigational aid/tool/system and useful especially in coastal areas, narrow channels and within high traffic and on high speed vessels, at night and on tankers.

Table 7 Attitude of respondents towards ECDIS

Favorable	Conditionally Favorable	Unfavorable
21 respondents	40 respondents	8 respondents
An important nav a aids/ tool / system (8)	**Conditions:**	Paper charts(3)
Lower workload (3)	Too much complicated (6)	Decreases nav skills (2)
Good at coastal navigation, channels and high traffic and high speed vessels, at nights and at tankers (3)	Training requirements (5)	Conventional methods (1)
Increase nav safety (2)	Over-confidence (5)	Relaxed (1)
Ease chart correction(2)	Conventional methods (visual and radar) (4)	Hardware problems(1)
Ease voyage planning(1)	Paper Chart (4)	
Support decision making(1)	Makes people lazy (decrease navskills) (3)	
Support OOW(1)	The quality of the user (3)	
	Common menu (3)	
	Needs to be more reliable software and hardware(3)	
	Master supervision (2)	
	With paper charts at special areas(1)	
	Without radar/AIS on ECDIS(1)	
	Alarms (1)	
	Ergonomy on the bridge (noise and brightness)(1)	
	More reliable inputs from other sources(1)	

In the second category, the respondents are favorable to ECDIS but they have some objections. They mentioned that ECDIS is too complicated, appropriate training is very important, it has to be used with conventional methods and paper charts and point out the danger of over-reliance on ECDIS and overconfidence of the officers.

The third category is totally unfavorable to the ECDIS. It is mentioned that the conventional methods and paper charts are more suitable than ECDIS; ECDIS decreases the navigational skills of OOW and make them over relaxed and lazy and also they point out the hardware reliability problems that they experienced. The factors that affect the attitude of respondents towards ECDIS are mentioned in Table 7. with their frequencies.

5. Conclusion

ECDIS plays a significant role in prevention of collisions and groundings as it improves SA by lowering workload and providing accurate and timely information to the officers. The data shows positive moderate correlations between "ECDIS improves SA of OOW" and the effect of ECDIS on prevention of collisions and groundings. It is concluded that ECDIS plays an import role in improving and maintaining SA only if the OOW has proper knowledge, skills, experience and it has reliable hardware and software. Although there is a high consensus on the benefits of ECDIS in improving navigational safety; being too complicated, requirement for appropriate training, importance of conventional methods and paper charts, danger of over-reliance on ECDIS, overconfidence of the officers, loosing navigational skills, being over relaxed and reliability of the systems are the main reasons for objection. ECDIS training programs shall also focus on the methods and procedures for improving SA of operators while navigating with ECDIS.

Limitations and further study. The study has been accomplished in only one institution and the respondents' experience with fully implemented ECDIS had been limited. For further study, the attitudes of mariners who had more experience with fully implemented ECDIS without using paper charts can be examined.

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