

Evaluation of S-100 ECDIS Based on S-10X Digital Maritime Safety Information

† HyunSoo CHOI · SeWoong OH* · DongWoo KANG** · MyongO Yoon***

† Student, Division of Disaster Science, Graduate School of University of Seoul / Researcher, Maritime Safety and Environmental

† Research Division, Korea Research Institute of Ships & Ocean Engineering, Seoul 02054, Republic of KOREA

*Researcher, Maritime Safety and Environmental Research Division, Korea Research Institute of Ships & Ocean Engineering

**Researcher, Maritime Safety and Environmental Research Division, Korea Research Institute of Ships & Ocean Engineering

***Professor, Division of Disaster Science, University of Seoul

Abstract : The IMO has established a regulation for the ECDIS installation on ships based on the IHO S-57 standards. The ECDIS supports sailors in achieving a safe voyage by using ENC's and monitoring the information of their ship. However, the S-57 standards were developed as edition 3.1 and prohibited revision for more than 20 years. So, the IHO developed a new standard as S-100 into the hydrography and maritime field instead of updating the S-57 to edition 4.0. In this study, the new S-100 ECDIS was developed and verified with ENC's and the digital maritime safety information by using a ship steering simulator and by conducting an on-board sea-trial test. It evaluated the impact on ship operations if the next-generation navigation support system is introduced. Based on this research, the S-100 ECDIS will generate improvements such as safe voyages by providing various of real-time safety information and up-to-date data to ship and sailors.

Key words : S-57, S-100, ECDIS, IMO, IHO, digital maritime safety information

1. Introduction

The International Maritime Organization (IMO) has established a regulation for the installation of an electronic chart information display system (ECDIS), which presents ship information in electronic navigational charts (ENCs) in real time on the monitors of navigation support systems. Using the ECDIS, the planning and navigation of routes can be realized digitally; this digital method has replaced the existing analogue methods (Hong et al., 2005). In addition, the mandatory installation of the ECDIS for vessels of ≥ 500 gross tonnes by the International Convention for the Safety of Life at Sea (SOLAS) was enforced from July 2012 and completed in stages over six years before July 2018 (Jung et al., 2015). The ECDIS is a navigation support system that assists sailors in achieving a safer voyage by using an electronic and automated process and monitoring information of their own ship, surrounding ships, and ocean status on one screen through ENC's (Lee, 2018). This system exhibits several advantages, such as automation of repetitive tasks and establishment of convenient route plans; further, the system can significantly reduce the risk of accidents as the sailors can actively acquire real-time

information at any time during the operation.

The current ECDIS is based on the S-57 standard published by the International Hydrographic Office (IHO), which first edition 1.0 was published in 1992. This standard was subsequently revised based on the feedback from equipment manufacturers and hydrographers. The IHO S-57 edition 3.1 was frozen in 2000 because simultaneously updating the ECDIS to comply with the revised IHO standard is difficult, as the ECDIS is operated at sea. If the IHO updates the ENC and ECDIS standards and it is not consolidated and unified with the system, the update can confuse sailors. The IHO discussed the update of the S-57 standard and finally decided in 2005 to expand the ISO 19100 series standard into the hydrography and maritime field and to develop it under the name "S-100 standard" instead of updating the S-57 to edition 4.0 (Korea Hydrographic and Oceanographic Agency (KHOA) project report, 2017). The S-100 standard was published as edition 1.0 in 2010 and reflects the latest trends such as symbol drawing and data exchange through online networks part, therefore edition 4.0 is currently in operation.

In this study, a next-generation international standard based S-100 navigation support system was developed in

† Corresponding author, troychoi@kriso.re.kr 042)866-3628

* osw@kriso.re.kr 042)866-3692

** dwkang@kriso.re.kr 042)866-3721

*** 5042yoon@naver.com 02)6490-5005

the form of an ECDIS, following the IHO S-100/10X standards, for resolving the limitations of the S-57 based navigation support system such as the current ECDIS. The S-100 ECDIS was verified with ENC's and digital maritime safety information using a ship steering simulator by conducting an on-board sea-trial test at the coastal sea of the Republic of Korea. The next-generation navigation support system was introduced into a ship, and it was evaluated whether the S-100 ECDIS can help resolve the limitations of the existing S-57-based ECDIS, improve operational safety, and reduce the actual workload of sailors. In addition, the maritime safety information defined by the IHO, which is based on S-100/10X, was quantitatively analyzed with respect to its completeness and utility for the S-100 ECDIS dissemination in the near future.

2. Status of ECDIS and Standards

As mentioned previously, the current ECDIS is a navigational support system for the portrayal of S-57 ENC's based on the S-57 standard edition 3.1, last revised in 2000. This makes it impossible for the ECDIS to utilize the acquired data and communication technologies in the maritime and ocean field developed since then. The standards have been maintained for more than 20 years without any further revision. Therefore, even if new ENC's are published, it would take a very long time for them to be reflected in the ECDIS and for port authorities worldwide to add newly constructed infrastructures and systems as objects for S-57 electronic charts. For ENC's, it is necessary to store updated data in a portable device such as a CD and then board the ship to install the data on the ship's ECDIS. Considering the ship's itinerary, the process of setting up the latest ENC's to the ECDIS is time consuming. In addition, the current S-57 product standard structure can only cover ENC's in vector format and not in 3D or time-series data.

Moreover, the current S-57 ECDIS sometimes impairs navigational safety because the internal format and components that make up the system are incomplete. A representative example is the artificial interpretation of the S-57 standard and the systems that are based on it. ENC's, which are essentially used in GPS plotters as well as certified navigation support systems such as ECDIS, were produced based on the S-57 standard 3.1 published in 2000. S-57 is a standard that requires humans to directly read

and interpret the text, figures, and tables of documents to develop a navigational support system. Therefore, the interpretation can differ depending on the ECDIS developers' understanding and analysis of the standard. For instance, in the past when the ECDIS quality and type approval certification were undertaken by DNV GL, a difficulty was encountered because the information displayed by the navigation support system was not the same for each equipment manufacturer. In addition, new information such as surface currents and virtual AtoN, which did not exist in the past, have been introduced. Therefore, following the development of industrial technology proves to be difficult, and updates are necessary to include this information in the ECDIS. However, because the S-57 standard is a physical document rather than a digital one, it is almost impossible to collectively reflect and update any revision to the ship's ECDIS worldwide. The IHO has frozen the S-57 standard as edition 3.1 to prohibit any further revisions to the standard, except for elements that could pose significant risks to safe navigation. In Addition, S-100 standard supports Plug-N-Play for navigational machine when user load a new version of standard or catalogue files, so it figure out S-57 standards limitation of updates and extension.

Table 1 IHO S-100/10X Product Specification

S-10X	Name of Product Specification
S-101	Electronic Navigational Chart
S-102	Bathymetric Surface
S-104	Water Level Information for Surface Navigation
S-111	Surface Currents
S-121	Maritime Limits and Boundaries
S-122	Marine Protected Areas
S-123	Marine Radio Services
S-124	Navigational Warnings
S-125	Marine Navigational Services
S-126	Marine Physical Environment
S-127	Marine Traffic Management
S-128	Catalogue of Nautical Products
S-129	Under Keel Clearance Management

The IHO recognized the problems associated with developing the current S-52/57 standard in a human-readable format. These include differing judgments depending on the interpretation of the interested parties, lack of scalability, and difficulty in updating the standard.

In 2020, the IHO released the S-100 standard as universal hydrographic data model edition 1.0. It uses machine-readable catalogs to address marine safety information such as tidal currents, water level, and bathymetric surface (KHOA project report, 2018). This standard is intended to provide all hydrographic data that are required for ship operation in the sea in a standardized format and data structure, and not only for displaying electronic schematics on the navigation support system, enabling the processing of dynamic and grid data.

The IHO has continuously expanded and revised the S-100 standard and published edition 4.0 in 2018. The official S-10X hydrographic product standards, which are derived from the S-100 standard, can be summarized in Table 1 (IHO website, 2020). Fig. 1 illustrates a blueprint when S-10X waterway data, which are produced based on the S-100 hydrographic product standards, are applied to actual sea navigation. It can identify S-102 bathymetric surface information that directly affects the safe operation of ships, as well as S-122 marine protected areas and S-124 navigational warnings.

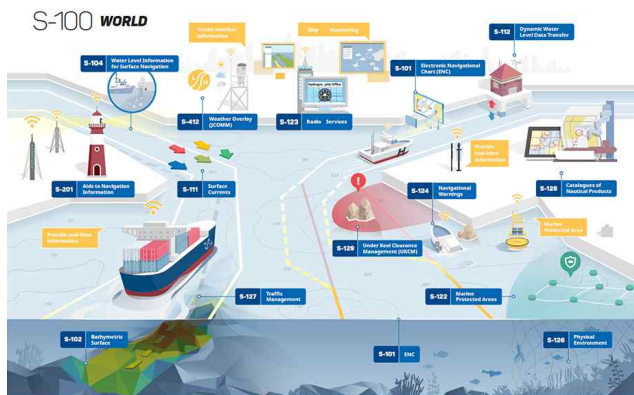


Fig. 1 S-100 World with S-10X Product Specification

3. Development of S-100 ECDIS

In this study, an S-100 test bed system was established using a self-developed S-100 ECDIS to verify the next-generation navigation support system based on digital maritime safety information. The system comprises a ship steering simulator and commercial S-57-based ECDIS equipment, as shown in Fig. 2. The ship steering simulator is on a Compact Sim scale, and the bridge is in the form of a cockpit similar to that of a real ship; it includes engine control and steering, ECDIS and RADAR consoles, ODD, and gyrocompasses. SAN Engineering's NAVIK S-57

ECDIS, which is currently used widely on commercial ships, was installed and configured in the same manner as in an actual ship environment. The S-100 ECDIS console was installed side by side with the S-57 ECDIS so that ship operators can easily identify and understand differences in the ENC portrayals through ECDIS following international standards such as S-57 and S-100.

S-100 ECDIS was developed with XSLT and LUA language and scripting reference to supports S-101 ENC and other S-10X Digital Maritime Safety Information. Grid data based on HDF-5 has been supported by S-100 ECDIS to cover S-111 surface currents and weather forecast information.

Apart from the S-100 test bed platform based on the ship steering simulator, a portable S-100 ECDIS, which can be connected to an AIS receiver and a GPS receiver, was set up. The S-100 ECDIS was operated at sea using an actual ship to conduct a real sea test.



Fig. 2 S-100 Testbed System

4. S-100 ECDIS Impact Evaluation

To perform the actual sea area shipboard test, the S-100 ECDIS was installed on the OCEAN2000 vessel, one of the survey ships of the KHOA. Laboratory testing of the S-100 test bed system was conducted using the ship steering simulator. The results demonstrated that the system's potential impact on ship operation could be evaluated and compared with that of the current S-57 ECDIS equipment. The system can also identify items that are expected to change and improve ship operation due to the provision of digital maritime safety information from the S-100 ECDIS equipment.

4.1 S-100 ECDIS Evaluation through Sea-trial Test

The S-100 ECDIS with an AIS receiver and a GPS sensor was installed on KHOA's Ocean 2000 vessel. Two

sets of S-100 ECDIS were installed in the bridge to enhance the sea trial and evaluation. To ensure the reception sensitivity and quality of acquired data of the AIS receiver and GPS receiver, the S-100 ECDIS was operated inside the steering room, and the actual receiver itself was installed on the top of the ship outside so that no shaded area was present. A separate S-100 test system was installed in the data analysis room, which serves as a back-of-bridge unit for monitoring purposes; a separate maritime communication network with land was not provided. As shown in Fig. 3, the vessel departed from Busan and passed near Geoje Island; then, it entered the Busan port again.

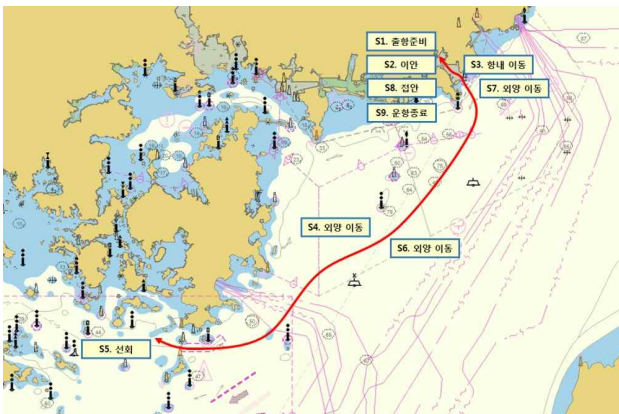


Fig. 3 Sea-trial Test Scenario

The main purpose of the sea trial test was to verify the national maritime safety information data based on the S-10X hydrographic data product specification developed by the IHO through the S-100 ECDIS. The chair of the working group under the IHO in charge of product specification, ship operators, and experts from overseas maritime safety information were selected as reviewers of the verification. One identified expert review comment was that the density of the current S-111 data and the symbol representation were extremely rough for the sailors to use, making the data less reliable. However, if the S-111 surface current information is displayed on the S-101 ENC, it may be unreadable because it overlaps with the other information on the ENCs.

In the past, the S-57 ECDIS provided only ENCs; however, the S-100 ECDIS displays maritime safety information in a digital format, as summarized in Table 1. Rather than providing and presenting all the information to the users simultaneously, interoperability is important for visibility; hence, displaying the information according to its

importance is essential. However, it has been difficult to make a precise judgment on accurate visibility because the IHO is still in the process of developing standards about interoperability of maritime safety information.

The S-111 surface currents and S-412 weather forecast are provided as a time-series form following the current product specification; however, the form should be dynamically streamlined such as Windy and that the trend of the forecast must be recognizable at a glance by the ship operator. The IHO has newly introduced the back-of-bridge concept by extending the front-of-bridge concept defined by the IMO in the SOLAS regulations. In this study, the role, data delivery, and route planning of the back-of-bridge and front-of-bridge concepts, which are required in actual operation to obtain information in real time, were verified.

4.2 S-100 ECDIS Evaluation through Simulator

To assess the practical impact of digital maritime safety information applied to the navigation support system, ships were operated by simulators by reproducing actual stranding accidents off the coast of Korea. Another goal was to determine whether the ship operator would be able to avoid the accident when digital maritime safety information was provided to the S-100 ECDIS at the point where the accident occurred.

To analyze ship-related accidents in the domestic sea, 95 accidents over the past 6 years were selected based on the re-decisions and maritime accident statistics provided by the Korean Maritime Safety Tribunal. Afterward, the causes of accidents were identified as 1) sleepiness, 2) drinking, 3) failure of the navigation support system, 4) carelessness, 5) neglect of safe depth or safety contour, and 6) insufficient maritime safety information. This study decided to verify accident causes 5 and 6.

The specifications of ships held in the simulators and the status of 3D maritime spatial data were analyzed to reproduce the accident situation in an environment similar to that in the actual sea. As a result, five cases in which maritime safety information can directly affect the navigation support system through a simulator-based virtual navigation were defined, as summarized in Table 2.

Table 2 Main 5 cases of ship grounding

No.	Ship accident outline
1	TongYoung, Fishing boat H85
2	JeJu, Ferry ship H1, 2019
3	Ulsan, Oil tanker J, 2019
4	InCheon, Tug boat T11, 2018
5	GunSan, Tug boat S5, 2019

The actual site of the accident for Case 4 is marked with a red cross in Fig. 4. The ship ran aground in a shallow area due to inaccurate estimation of the vessel's draft and safety depth, which was the cause of the accident. The site was approximately 0.24 miles away from the Incheon Port No. 16 light buoy at 174° in the true direction, and a passageway was included in the electronic chart for safe entry and departure of ships. However, the vessel entered shallow water area because the sailors were misled by the safe depth information generated by human error in using the ECDIS.



Fig. 4 Ship Accident spot of Case 4

A route plan was created through the S-100 ECDIS developed in this study, as shown in Fig. 5. Here, Wp1 is the starting point, Wp2 the intermediate point, and Wp3 the accident location. The graph in Fig. 6 shows the information of the S-102 bathymetric surface according to the route information. The gray part at the top represents the draft of the ship, whereas the blue part below it represents the under-keel clearance (UKC) such as free depth. The light blue part below it indicates the depth of water that the vessel must maintain, and the lowermost part indicates the bathymetric surface of the bottom.

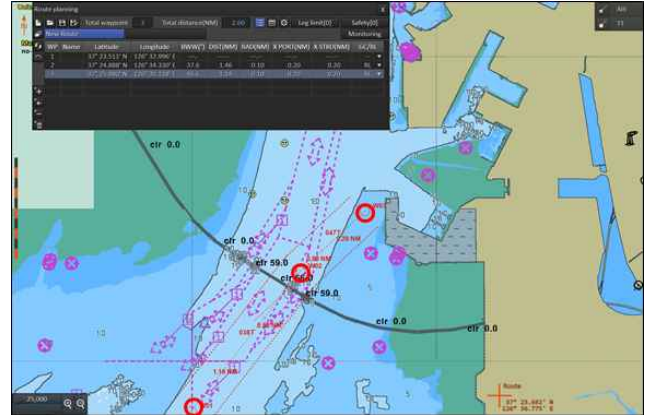


Fig. 5 Route Plan by S-100 ECDIS

The dangerous values on the graph indicate a situation when the floor of the water drain and the area corresponding to the seabed topography are created. The bottom part of the ship touched the bathymetric surface confirming that a stranding accident had occurred. Using a ship steering simulator, the operation was initiated in accordance with the planned route in Fig. 5, which showed a dangerous stage near the accident site. Then, as indicated by the red circle in Fig. 6, the bottom of the ship was confirmed to hit the bottom of bathymetric surface, thus causing the actual stranding accident. The ship-controlled simulator was shut down indicating the occurrence of the accident.

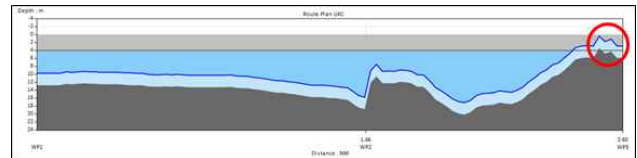


Fig. 6 Case 4 UKC Graph of Case 4 Route

The assessment of domestic sailors and navigation equipment manufacturers in using the S-100 ECDIS and the ship steering simulator for the aforementioned five actual stranding accidents are summarized as follows:

- ① The current S-57 ECDIS provides only the safe depth included in the ENCs, and the task is excessive because the sailors must check the entire depth when establishing a route plan
- ② The S-100 ECDIS can establish an economical and safe route by expressing the UKC value according to the draft as well as the safe depth for each Wp when the sailors plan a route.
- ③ The symbols of the S-101 ENCs are almost the same

as those of the current S-57 electronic chart; hence, no significant additional training costs will be required.

④ Presenting various digital maritime safety information including that of the S-101 ENC's on one screen lowers the user's visibility. Hence, either a 2-window ECDIS should be installed or the number of displayed symbols and information should be appropriately adjusted.

5. Conclusion

In this study, a usability assessment of the S-100 ECDIS developed by the IMO and IHO was conducted to determine its possible impact on ship operation if the next-generation navigation support system is introduced.

First, concerning the evaluation of completeness as a product standard for the S-101 ENC's and S-10X maritime safety information introduced in the S-100 ECDIS environment, the data produced by experts in international standards and ENC's publishing were verified and items requiring revision of product standards were identified. As a result, the requirements for the density of S-111 surface currents should be improved, and the forecast information required for route planning should be streamlined to facilitate the identification of forecasted trends in the data.

The S-57 ECDIS and S-100 ECDIS were operated side by side to reproduce grounding accidents using the ship steering simulator. Then, the impact of introducing the next-generation navigation support system on ship operation was assessed by domestic sailors and navigation equipment manufacturers. Consequently, although the current S-57 ECDIS was unable to display the UKC values in accordance with the drift of the vessel, the S-100 ECDIS was able to confirm through graph 1 that there was no UKC of the vessel at the point of the actual accident.

Based on this research, the S-100 ECDIS will bring the following improvements: 1) securing operational safety by providing more detailed information, 2) reducing the workload of sailors, and 3) making it easier to comprehend predictive information by supplying streamlined or time-series data. Moreover, information is provided digitally instead of buying books and booklets; therefore, book expenses and storage will be reduced. In addition, the introduction of the S-100 ECDIS is expected to address the limitations of the current S-57 ECDIS, while also providing the latest communication and data processing technologies. This will lead to several advantages, including economic operation and better shipboard information management, for

both ship operators and shipping companies.

As a result, S-100 ECDIS was evaluated with maritime safety information. The new ECDIS provides digital data as digital format to users, so sailors can utilize it anytime and overlay it to ENC's in ocean. For example in route planning process, sailors can set start and destination with waypoint, S-100 ECDIS will verify route with ENC's features and safety depth and notify results to ship. As described in several preliminary studies, ship accidents at sea are mainly due to human factors. For the safe navigation of ships, both the distribution of next-generation navigation support systems such as the S-100 ECDIS and training on how to use the correct equipment for ship operators using actual equipment should be implemented (Lee et al., 2016). Because the S-57 ENC's and S-101 ENC's have almost the same features and symbols on the screen, there will be no difficulty for existing ship sailors to learn the new S-100 ECDIS and S-101 ENC's. However, surface currents and weather forecast information, which were provided in the form of NAVTEX or short messages in the past, will be provided in a digital form; thus, basic education for understanding the information is deemed necessary. Furthermore, the IMO and IHO must ensure the completeness of standards and product specifications for the S-100 ECDIS and digital maritime safety information with respect to symbols and interoperability. A prior ergonomic product design based on usability evaluation is necessary, but S-100 ECDIS with ENC's and maritime safety information is supposed to provide enhanced safe voyage. In addition S-100 ECDIS offers ship status and route information as real-time with dangerous prediction, so sailors can achieve a safe voyage.

Acknowledgements

This research was supported by a grant from Endowment Project of "Development of core agent modelling and interaction technology for maritime traffic analysis" funded by Korea Research Institute of Ships and Ocean Engineering (PES3600).

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Received 29 September 2020

Revised 16 October 2020

Accepted 22 October 2020