Časopis Pomorskog fakulteta Kotor – Journal of Maritime Sciences (JMS)
god. 24, br. 2/2023; Vol. 24, No. 2/2023; November, 2023

DOI: https://doi.org/10.56080/jms231104 UDC: 656.61.052
Review paper

Overview of the Development of Nautical Charts*

Jakša Mišković†, Ivica Pavić, Pero Vidan, Srđan Vukša

Abstract: Nautical charts are one of the basic aids for safe navigation. Their development went through different phases and is related to the development of technology. The development of nautical charts has gone through certain phases. One can talk about the phases of the development of paper and electronic nautical charts. Paper charts have evolved from the dawn of maritime navigation (or from its earliest periods) to the advent of electronic charts. Recent technological developments have enabled the creation and use of electronic nautical charts in the formats of Raster Navigational Chart (RNC) and Electronic Navigational Chart (ENC). ENCs now take precedence over paper charts and RNCs and will gradually replace RNCs and paper charts on some types of SOLAS ships. The International Hydrographic Organization (IHO) has developed standards for paper, raster, and vector charts. After developing standards for existing ENCs, the IHO has developed a set of standards called S-100 as the basis for developing a new type of ENC. These charts will soon replace the existing ENC. This paper provides an overview of the development of nautical charts with a particular emphasis on the IHO standards.

Keywords: Nautical charts, Paper charts, Raster navigational charts, Electronic navigational charts.

1. Introduction

The official term of the nautical chart is defined in the International Convention for the Safety of Life at Sea 1974 (SOLAS). According to SOLAS regulation V/2-2, a nautical chart is a special-purpose map or a specially compiled database from which such a chart is derived, that is issued officially by or under the authority of a government, authorized hydrographic office, or other relevant government institution, and designed to meet the requirements of marine navigation [1]. This definition equates paper and

* An earlier version of this paper was presented at the 2nd Kotor International Maritime Conference – KIMC 2022, Kotor, Montenegro.

† Corresponding author

electronic nautical charts. In addition, according to this definition, charts must be issued by official governmental organizations or institutions. All other charts are unofficial or private charts. These charts are issued by private organizations and do not have to comply with SOLAS requirements for safe navigation [2]. Nautical charts are divided into official and unofficial (private) nautical charts, with a distinction made between paper and electronic charts based on the format of the nautical charts. The electronic charts include official RNC and ENC charts and unofficial electronic charts.

Paper charts were the only type of nautical charts until recent decades. During the centuries of use, their production was not uniform at the international level. However, since maritime navigation is primarily international, it was necessary to achieve some degree of standardization of the information on paper charts. For this reason, the information on paper charts has been standardized. An important role was played by the IHO, which developed the standard "Regulations of the IHO for International (INT) Charts and Chart Specifications of the IHO" [3]. Although this standard refers to the INT, its development, together with other relevant IHO documents, has largely standardized the paper charts that form the basis for the electronic charts.

Electronic charts are developed by national hydrographic organizations and private companies [4]. Private companies develop their unofficial charts and display systems. Official electronic charts are produced according to the relevant IHO standards. In addition to these standards, the IHO has developed the World-wide Electronic Navigational Chart Data Base (WEND) concept. The WEND concept consists of a set of principles for the cooperation, production, and distribution of ENCs [5-7]. ENCs produced and updated based on IHO standards and distributed according to the WEND are intended for use in ECDIS. Due to certain limitations of existing ENC, modern requirements, and future concept of e-navigation, a new set of IHO standards has been developed. The new standards relate to the future S-100-based ENC. Special-purpose electronic charts are charts used on warships, by maritime pilots, in ports, and confined waters. In addition to ENC, RNC must also be mentioned. RNC can still be used in ECDIS, in areas not covered by ENC.

The article consists of five sections. The introduction describes basic terms, types, and main features of nautical charts. Section two describes the development and standardization of paper nautical charts. Section three presents the development of electronic charts based on their formats and standards. Section four describes ENCs for specific users and the recent development of standards and formats for future ENC. Section five provides conclusions.

2. Paper nautical charts

Paper charts are thought to date from the earliest days of navigation. Some simple nautical charts from ancient times have been preserved [8]. From II. Century BC, Claudius Ptolemy's Geography is the most important geographical and cartographic work of ancient times, which formed the basis for the development of European cartography [9]. In addition, since the early modern period, pilot charts were used, often called compass charts because they contained the compass rose(s) [8]. From the Middle Ages, it is worth mentioning the development of printing machines, which made it possible to reproduce nautical charts and trade with them, as well as the development of chart projections, especially the Mercator projection, which is still used today [8, 10]. The centers of cartography at that time were also the centers of maritime trade in the Mediterranean [9]. Later, with the development of science, nautical charts were developed based on scientific principles, using data collected by hydrographic surveys and positioning methods developed at that time.

In the new era, international geographical and hydrographic congresses made an important contribution to the development of marine cartography. Of outstanding importance to the development of cartography and hydrography was the establishment of the International Hydrographic Bureau, as the predecessor of the IHO. The role of the IHO in the development of paper charts is related to the standardization of the display of objects (symbols) [11], i.e., the content of charts. This has been achieved through the development of IHO resolutions in publication M-3 and standards S-4 and S-11. IHO Publication M-3 contains (among other resolutions for nautical charts and publications) IHO general resolutions and Regulations of the IHO for International (INT) Charts and Chart Specifications of the IHO [12].

IHO Standard S-4 consists of three parts and contains detailed general information, chart specifications, schemes, maintenance, framework, topography, hydrography, aids to navigation, text, maintenance, and agreed symbols and abbreviations of INT charts [3]. In this way, the technical elements of content and layout have been standardized. In addition to the S-4 standard, the IHO has developed three complementary publications, referred to as INT 1, 2, and 3. Since the nautical chart is a simplified representation of reality, its content is represented with symbols and abbreviations. For this reason, the publication INT 1 contains a key to the symbols and abbreviations, the meaning, and the translations of the terms used on the paper charts [13]. INT 2 contains specimens of boundary patterns, graduation, grids, and linear scales published in the form of a chart

[11, 14]. INT 3 is also published in the form of a chart by the United Kingdom Hydrographic Office (UKHO) and consists of a fictitious area with as many examples as possible of the use of S-4 [11, 15]. The IHO standard S-11 contains the objective, concept, and procedures for the creation and maintenance of INT chart schemes [16]. These standards and resolutions are interrelated and represent a series of IHO actions aimed at developing a uniform scheme with agreed-upon scales and worldwide coverage of INT charts [16].

Although these standards were not directly applicable to national nautical charts, they still influenced the minimization of differences between them. The national hydrographic organizations maintained certain peculiarities in the production of their paper charts [11], so they sometimes differed according to the publisher, but these differences were not of crucial importance, since there is a commonly agreed key for the symbols and abbreviations used on paper charts.

In a sense, the development of paper charts stopped after the development and wide use of electronic charts. However, it can be said that some electronic charts are based on paper charts. This is especially true for the electronic charts created based on hydrographic survey data that date back to the time when paper charts were created.

3. Development, formats, and characteristics of electronic charts based on IHO standards

The term "electronic chart" is a collective term for various types of shipborne digital GIS, whose core function is the graphical display of chart information [17]. This chapter gives an overview of the development of formats and main features of official electronic charts according to the basic IHO standards.

3.1. Development of electronic charts

The idea of developing electronic charts is not new. It dates back to the 1970s. Although not directly related to electronic charts, it is important to mention the development of radio navigation systems, integrated bridge projects, and plotter systems that aim to integrate data from navigation sensors with certain automatic position display capabilities, usually on plotters that use paper charts [18].

In the 1970s, states, academia, oil production companies, and manufacturers of navigation and electronic equipment participated in the development of electronic charts [4]. This decade is characterized by the absence of standards and different directions in the development of electronic charts, ranging from purely local to a broader application of these charts. After this initial phase, private chart makers played an important role in the development of electronic charts. They were a step ahead of the IHO and national hydrographic organizations in the field of electronic chart production. In the late 1980s, DX -87 was developed by the IHO as the first international standard for the exchange of digital data. At that time, eight national hydrographic offices were producing chart databases according to their formats [4].

The last decade of the 20th century saw the continued development of IHO standards for ECDIS. An official ECDIS definition was adopted. The IHO WEND committee was formed. This committee developed the WEND Principles from which the concept of producing, distributing, and updating ENC was developed. The IHO also developed a standard for chart content and display aspects.

In the 2000s, ECDIS was incorporated into the SOLAS Convention provisions and became mandatory equipment for certain types of ships. The IMO developed the implementation plan for ECDIS. National hydrographic organizations produced ENC cells to improve the coverage of ENC. A system for distribution, updating, and quality control of ENC by Regional Electronic Charts Coordinating Centers (RENCs) was also developed.

Over the past twelve years, coverage of ENC has increased significantly. The process of implementing ECDIS following IMO requirements has been completed. The S-100 standard has been developed. The use of RNC and paper charts are gradually being reduced. Some national hydrographic organizations are working to implement new standards for ENC through various tests, demonstrations, and sea trial projects. Figure 1 shows significant events in the development of electronic charts.

1970 - 1979

- Late 1970s; Offshore precise navigation system - Mackenzie River
- 1979; Precise Intercoastal Loran Translocator (PILOT) project

1980 - 1989

- 1983; ViewNav Master Mariner System by Mortimer Rogoff; IHO Sub-Committee on future Chart Design
- 1984; IHO Committee on the exchange of digital data
- 1986; IHO Commite on ECDIS; Joint IMO/IHO Harmonization group on ECDIS
- 1987: IHO adopted DX-87 standard on Exchange of digital data
- 1988 IMO model of electronic chart data
- 1989 IMO provisional performance standards for ECDIS

1990 - 1999

- 1992 S-57 adopted by IHO; WEND Committe established
- 1993; ARCS prototype was launched
- 1994; S-57 V.2 approved by IMO MSC
- 1996; S-57 Ed. 3.0 released by IHO; ARCS products made available
- 1998: IMO RCDS Ammendments to ECDIS product specifications
- 1999; RENC NE (PRIMAR) established

2000 - 2009

- 2002; ECDIS included in SOLAS Chapter V; PRIMAR RENC splitted into PRIMAR and IC-ENC RENC
- 2008; IMO ECDIS Implementation plan

2010 - now

- 2010; IHO adopted S-100 standard
- 2012; ECDIS - mandatory equipment for newbuilding ships
- 2016; S-102 demonstrator project initiation (Norvay)
- 2017; S-100 projects in Canada
- 2018; Full implementation of ECDIS
- 2019; S-100 Sea trial project (South Korea)

Fig. 1 - *Significant events in the development of electronic charts* [4, 17 – 20].

3.2. Formats and characteristics of electronic charts to use in ECDIS

Official electronic charts have been developed in two formats. These formats are RNC and ENC. RNC production is faster and easier than ENC production, but because of the limitations of RNC, ENCs have been developed.

RNC is based on raster technology, where images are composed of picture elements - pixels. The pixels contain information about color and brightness. RNC is created by simply scanning a paper chart. After scanning, the image is saved in a digital format. The rectangular grid of pixels is created during scanning so that the pixels occupy a specific position in the column and row. The main advantage of RNC is the very short production time, which is equal to the time for scanning a paper chart. The quality of RNC depends on the quality of the scan. The higher the scan resolution, the higher the quality of the RNC, but also the higher the number of pixels. The larger the number of pixels, the more memory is needed to store the RNC. Since most paper charts are created in A0 format, the RNC typically requires 10 MB of storage space after scanning [17]. Although there are options for data compression, RNC storage can be a limiting factor. An RNC represents a digitally stored paper chart. The data structure of the RNC corresponds to the data of the paper chart. Thus, an RNC is a digital chart based on analog data. Major producers of RNCs are the UKHO (British Admiralty) and the US National Oceanic and Atmospheric Administration (NOAA) [17]. The UKHO has produced a total of more than 3,000 official RNCs. The UKHO has developed the Admiralty Raster Chart Service (ARCS). ARCS provides global coverage and weekly updates of RNCs [21]. NOAA produces RNCs which are official digital copies of paper charts produced by the US Office of Coast Survey. NOAA's RNCs are updated weekly through the distribution of electronic "patches" [22]. It is also important to note that NOAA's RNCs do not comply with U.S. Coast Guard requirements for merchant ships. Although their use is permitted under IMO regulations, U.S. national regulations require the use of vector charts because the U.S. coastal area is covered by the appropriate ENC [23]. NOAA has announced that RNC production and services will be canceled by January 2025 [24].

For RNC to be used in ECDIS under IMO requirements, the system can be operated in "dual fuel" mode as a Raster Chart Display System (RCDS) and ECDIS. In this case, the RNC must meet the requirements of IHO Standard S-61. The standard contains definitions for RCDS and RNC, as well as requirements for RNC updates by Notices to Mariners (NtM). RNC is an official chart issued by a hydrographic organization by scanning an official paper chart. In addition, the RNC must provide at least the same safe navigation capabilities as a paper chart. The RNC must be automatically updated by the official weekly NtMs, and the updates must be recorded in the ECDIS [25].

Because of the limitations of the RNC, ENCs have been developed. ENC is based on vector graphics. Vector technology can ensure that each image element corresponds to a real object and provides additional information about that object. The ENC, which is organized based on the S-57 standard, can be considered an "intelligent" chart, where the amount of information can vary and be less than the total amount of information contained in the ENC. Therefore, the user can choose to display all or only certain information on the ECDIS screen. To achieve this, ENC is organized in the form of thematic layers. In this way, different topics can be separated and placed in different thematic layers, and the number of thematic layers is not limited. This means that the ECDIS operator can remove information that he does not need at a certain moment or display additional information that he does need at that moment. For example, it is possible to display all depths shallower than the selected (critical or a default) depth, remove the display of colors and sectors of lights and buoys during daytime navigation, set certain alarms, or change the background of the display on the ECDIS screen. An "intelligent" chart organized in this way has numerous advantages over a classic paper chart whose data cannot be changed, as is the case with ENC. ENC requires much less computer memory than RNC. This is very important for the overall memory capacity of the computer on which the charts are loaded and displayed. This feature is also important for ENC data transfer.

The IHO has developed a set of standards for ENC. Standard S-57 is the basic standard for ENC. The IHO developed this standard in 1996. S-57 Edition 3.1 is currently in effect [26]. The S-57 standard defines the principles and organization of vector data representation and the requirements to produce ENC. Based on this standard, national hydrographic organizations create ENCs uniformly. Thus, the uniformity of ENC in ECDIS is achieved on a global scale. The standard consists of the S-57 main document and appendices A and B [17, 26]. The basic contents of the main document are the theoretical data model and the data structure [26]. According to the S-57 approach, the production of ENC is the modeling of the real world [4]. The basis of the theoretical data model is the entities (real or abstract objects, spatial objects, other objects, or events) from the real world that are relevant for hydrography, i.e. for representation on an electronic chart. The theoretical data model is based on the vector representation of spatial objects. This means that the characteristics of spatial objects are displayed using a vector approach to data encoding. The data structure determines how the formatting or encapsulation of the data is done. Then, the data is encoded and organized in the prescribed manner, and an exchange set is formed, consisting of one or more hierarchically organized files. In this way, it is possible to exchange or transfer data between several computers. At the same time, in addition to the transfer, it is necessary to enable the conversion of data into the format System ENC (SENC) and data transfer for ENC updates [4, 26].

Appendix A consists of an object catalogue and an attribute catalogue [27, 28]. It contains all objects and attributes that can be associated with objects. The object catalogue classifies, describes, and labels in a standardized manner all real-world objects and agreed-upon objects found on nautical charts. The catalogue contains all objects that can be found in the publications INT 1 and S-4. These objects are displayed in digital form and coded in a standardized manner. Since each hydrographic organization creates its ENCs according to the object catalogue, it is not possible to create other objects or assign different attributes to them than those standardized at the IHO level. The object catalogue, as a key element of the S-57 standard, allows organizing data and creating ENC in a standardized way. The attribute catalog contains a list and defines all attributes and their domains [17, 28].

Appendix B contains product specifications and rules for ENCs to be used by hydrographic organizations in the production of charts. The product specifications and basic rules for ENC are the division of ENC into cells; mandatory, allowed, and prohibited attributes; horizontal and vertical datum; coordinate system; depths, heights, and distances; data organization; numbers; objects that change over time; and updating the dataset [19, 29]. According to Appendix B, ENCs are organized into cells, where an ENC cell can be considered the equivalent of a paper chart. ENCs are classified into six categories, from overview to berthing charts, depending on the navigation purpose [26, 30]. ENCs created and updated according to the S-57 standard and other relevant IHO standards meet IMO requirements for use in ECDIS.

4. ENCs for specific users and S-100-based ENCs

To date, several types of ENCs have been developed for specific user groups. These are electronic charts for warships, bathymetric ENC (bENC), and high-density bathymetric ENC (HDbENC). The HDbENC is also referred to as HDENC in the literature. New ENCs based on the S-100 standard are currently being developed as part of some specific projects.

Electronic charts are charts specifically designed for use in Warship ECIDS (W-ECDIS). The North Atlantic Treaty Organization (NATO) has developed performance standards for W-ECDIS. W-ECDIS is an IMOcompliant ECDIS capable of using additional electronic chart data (in S-57, NATO DIGEST VPF /DNC, and RNC formats) and displaying additional military layers (AMLs) [17, 19]. The AMLs are intended to meet the non-navigational requirements of NATO and contain maritime geospatial data for defense users in a standardized digital format [17, 19, 31]. The design of the AMLs is based on the requirements of the naval (military) missions and applications for which product specifications have been or are being developed, such as flight aeronautical information, practice and exercise areas, Q-routes, anti-surface defense data, amphibious and mine warfare data, etc. [31]. Therefore, AML contains additional geospatial information compared to classical S-57-based ENC.

A bENC is an S-57-based chart with larger-scale and high-density bathymetric data intended for use by port authorities and pilots in confined waterways [17]. A bENC provides additional bathymetric information and denser contour lines, so it better represents seafloor bathymetry than the classic ENC. These charts can contain very recent high-density hydrographic survey data [17], making them suitable for use in ports or as bENC layer on portable pilot units (PPU). These charts are not official ENC, and they are not intended for use in ECDIS. Unlike bENC, HDbENC is a chart where the interval between bathymetric contours is one meter or less and where more detailed port infrastructure information is added to the chart data. The additional bathymetric information is integrated into the base ENC dataset [32, 33]. These charts aim to provide higher-density contour intervals than traditional paper charts (and ENCs based on paper chart data). In some cases, these charts allow ships to navigate in waters indicated as dangerous on the ECDIS when in fact the ship is still safe, and mariners can set appropriate safety contour with greater precision, efficiency, and confidence. HDbENC can be used in ECDIS and the PPUs so that both pilots and officers have the same information about safety margins in confined waters [33, 34].

Future ENCs for use in IMO e-navigation and with additional navigational features will be based on the S-100 standard. S-100 (formerly known as S-57 Edition 4.0) became effective in 2010 [17, 19]. IHO S-100 introduces the "Universal Hydrographic Data Model" as the basis of the IMO e-navigation concept. Based on this model, it is planned to develop a whole new set of standards covering a wide range of marine data. S-100 is not a simple standard. It is a concept or platform for the development of official digital products and transfer standards [4, 17] that will not only address the shortcomings of the S-57 standard but also avoid its limitations. The goal of the S-100 concept is to extend the use of hydrographic data and products to a wide range of users. It provides a framework for the development of the next generation of ENC and other digital products. S-100 is based on the concept of registers, in which catalogues of features and portrayal catalogues are machine-readable so that data and data structures can be updated through "plug and play". In addition, a new product specification will contain new features and attributes that will be included in new ENCs [4, 17]. All data products from the S-100 registries will be interoperable and allow end users to integrate data [17]. For example, new applications of the data products include high-density bathymetry and seafloor classification, and the standard will be extensible to future applications such as 3-D, time-varying data, and web-based services [19, 35], and will enable advanced three-dimensional dynamic display of bathymetry and topography data [18]. The new ENCs will be very (but not completely) different from the S-57-based ENCs. Therefore, backward compatibility will allow the conversion of data from ENC from S-57 to S-101 [17, 35]. The S-100 standard is under continuous development. Currently, S-100, Edition 5.0.0 from 2022 is in effect [35].

5. Conclusion

The development of nautical charts has continued from the early days of maritime navigation until today. In recent decades, this development has been dynamic in terms of electronic charts and display systems development and application. The main players in the system of production and standardization of official electronic charts are the national hydrographic organizations and the IHO. The IHO has developed a comprehensive set of standards for all types and formats of official nautical charts. The standards govern chart production, distribution, data protection, and updating. In this way, end users can have reliable and up-to-date charts. The development of RNC and ENC and their application in ECDIS have improved, accelerated, and increased the reliability of maritime navigation. As far as marine cartography is concerned, global shipping is in a dynamic phase. Currently, both paper and electronic charts can be used on ships. The use of paper charts and RNCs are gradually being reduced while projects for new, future ENCs are being developed. The IHO is currently developing a new set of standards based on the S-100 concept for future ENCs. The future ENCs will have several advantages over the existing ones. Their creation will be a lengthy and expensive process. This process will require a relatively high level of coordination among all the organizations and services involved. The development and application of these charts will certainly improve navigation safety, but only if the charts will be based on data from a modern hydrographic survey.

References

[1] IMO. *The International Convention for Safety of Life at Sea (Consolidated edition 2020)*, IMO Publishing, London, UK, 2020.

[2] IHO S-66. *Facts about Electronic Charts and Carriage Requirements, Edition 1.1.0*, International Hydrographic Organization, Monaco, 2018.

[3] IHO S-4, *Regulations of the IHO for International (INT) Charts and Chart Specifications of the IHO, Edition 4.9.0*, International Hydrographic Organization, Monaco, 2021.

[4] P. Thornton. *The ECDIS Manual, reformatted first edition*, Witherby publishing group, Edinburgh, 2016.

[5] IHO S-65. *Electronic Navigational Charts (ENCs) "Production, Maintenance and Distribution Guidance", Edition 2.1.0*, International Hydrographic Organization, Monaco, 2017.

[6] IHO M-3 Res 1/1997. *Principles of the Worldwide Electronic Navigational Chart Database (WEND) & its Annex (Guidance for Establishment of ENC Production Boundaries)*, as amended IHC 18 & 40/2014 3 & 36 Rev1/2017, International Hydrographic Bureau, Monaco, 2017.

[7] H. Hecht, WEND and RENC: Keywords for IHO's Distribution System for ECDIS Data - An Evaluation of Terminology and Concept, *International Hydrographic Review*, Vol 1, No. 1, (New series), July 2000., International Hydrographic Bureau, Monaco, 2000., p. 81-84.

[8] J. Kasum, *Doprinos optimizaciji reambulacije primjenom elektroničkih I informatičkih tehnologija, thesis (unpublished)*, Faculty of maritime studies Rijeka, Rijeka 2012., p. 4.

[9] P. Blažević, R. Busatto, and D. Radić. *Novi i poboljšani svijet, Zbirka pomorskih karata I peljara Hrvatskog pomorskog muzeja Spli*t, Hrvatski pomorski muzej Split, 2020., p. 7.

[10] *Pomorska enciklopedija - pomorske karte, kartografija, Part 3, 2nd Edition*, Jugoslavenski leksikografski zavod, Zagreb, 1976, p. 481 and 501.

[11] T. Duplančić Leder, N. Leder, Povijest publikacije Znakovi i kratice na pomorskim kartama u izdanju Hidrografskog instituta, *Geodetski list*, No. 3 2010, Hrvatsko geodetsko društvo, Zagreb, p. 193–215.

[12] IHO M-3. *Resolutions of the International Hydrographic Organization, 2nd Edition 2010 - Updated April 2022*, International Hydrographic Organization, Monaco, 2022.

[13] IHO INT 1. *Symbols and Abbreviations used on Paper Charts, English version, Edition 8*, International Hydrographic Organization, Monaco, 2020.

[14] IHO INT 2. *Borders, Graduation, Grids and Linear Scales, 4th Edition*, Netherlands Hydrographic Service on behalf of the International Hydrographic Organization, 2007.
[15] IHO INT 3. *Use of Symbols and Abbreviations, Edition 5*, The United Kingdom Hydrographic Office on behalf of the International Hydrographic Organization, 2011.
[16] IHO S-11. *Guidance for the preparation and maintenance of international (INT) chart and ENC schemes and catalogue of international charts, Edition 3.1.0*, International Hydrographic Organization, Monaco, 2018.
[17] H Hecht, B. Berking, M. Jonas, and M. Wöster. *The Electronic chart fundamentals, functions, data, and other essentials, A textbook for ECDIS use and training, Fourth edition*, Geomares publishing, Lemmer, The Nederlands, 2017, p. 28, p. 60-62 and p. 442-444.
[18] N. Kjerstad. *Electronic and acoustic navigation systems*, Norwegian Institute of Science and Technology, Alesund, Norway, 2016; p. 2-175
[19] A. Weintrit. *The Electronic Chart Display and Information System: An Operational Handbook*, CRC Press/Balkema, The Nederlands, 2009, p. 205, 206, and 212.
[20] IHO. *Enabling the Decade of S-100 Implementation*. [Online]. Available: https://iho.int/uploads/user/About%20IHO/Council/council3/C3_2019_04.1B_EN_S100%20Showcase%20Consolidated%20October%2014.pdf.
[21] Admiralty. *Admiralty Raster Chart Service*. [Online]. Available: https://www.admiralty.co.uk/charts/digital-charts/admiralty-raster-chart-service.
[22] NOAA. *NOAA Raster Navigational Charts (RNC)*. [Online]. Available: https://www.fisheries.noaa.gov/inport/item/39966.
[23] NOAA. *NOAA Raster Chart Products*. [Online]. Available: https://nauticalcharts.noaa.gov/charts/noaa-raster-charts.html.
[24] *Office of Coast Survey news and updates. Coast Survey to shut down the Raster Navigational Chart Tile Service and other related services*. [Online]. Available: https://nauticalcharts.noaa.gov/updates/coast-survey-to-shut-down-the-raster-navigational-chart-tile-service-and-other-related-services/.
[25] IHO S-61. *Product Specification for Raster Navigational Charts (RNC), 1st Edition*, International Hydrographic Bureau, Monaco, 1999.
[26] IHO S-57. *IHO Transfer Standard for Digital Hydrographic Data, Edition 3.1*, International Hydrographic Bureau, Monaco, 2000.
[27] IHO S-57 *Appendix A. IHO Object catalogue, Edition 3.1*, International Hydrographic Bureau, Monaco, 2000.

[28] IHO S-57 *Appendix A. IHO Object catalogue, Chapter 2 Attributes, Edition 3.1*, International Hydrographic Bureau, Monaco, 2000.
[29] IHO S-57 *Appendix B.1. IHO Object catalogue, ENC Product Specification, Edition 2.0*, International Hydrographic Bureau, Monaco, 2000.
[30] R. Becker-Heins. *ECDIS Basics, A guide to the Operational use of Electronic Chart Display and Information System, First edition*, Geomares publishing, Lemmer, The Nederlands, 2014, p. 73.
[31] NATO AML Handbook, *Additional Military Layers, Information superiority in the maritime environment, Edition 4*, August 2016; p. 5-17.
[32] A. Sanchez, A. Di Lieto and V. Bosselman-Borsos, "A practical approach to the production of ENC with high-density bathymetric content," *The International Hydrographic Review*, Nr. 22, p. 7–17, Nov. 2019.
[33] IHO S-65 Annex A. *High Density (HD) ENC Production and Maintenance Guidance, Edition 1.0.0*, International Hydrographic Organization, Monaco, 2020.
[34] Admiralty. *New HD ENCs available in ADMIRALTY Vector Chart Service*. [Online]. Available: https://www.admiralty.co.uk/news/new-hd-encs-available-admiralty-vector-chart-service.
[35] IHO S-100. *Universal Hydrographic Data Model, Edition 5.0.0*, International Hydrographic Organization, Monaco, 2022.

Submitted: 11/04/2023
Accepted: 20/06/2023

Jakša Mišković,
Faculty of Maritime Studies Split, Ruđera Boškovića 37, 21000 Split, Croatia
Email: jmiskovi1@pfst.hr

Ivica Pavić,
Faculty of Maritime Studies, University of Split, Ruđera Boškovića 37, 21000 Split, Croatia
Email: ipavic71@pfst.hr

Pero Vidan,
Faculty of Maritime Studies, University of Split, Ruđera Boškovića 37, 21000 Split, Croatia
Email: pvidan@pfst.hr

Srđan Vukša,
Faculty of Maritime Studies Split, Ruđera Boškovića 37, 21000 Split, Croatia
Email: svuksa@pfst.hr