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Analysis of Benefits for ENC S-101 Navigation Data Users in New S-101 Coding Format

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ABSTRACT: This article describes the benefits of data transit from S-57 to S-101 format, for the recipients of ENC navigation data as well as what are the goals and advantages of introducing the new format, the current technology and basic technological principles of database upgrade. A comparative analysis was carried out of depth data coding in both standards based on IHO published, actual specifications.

1 INTRODUCTION

The safety of marine transport depends largely on the correct position of a marine vessel: the methods of obtaining position as well as the correct, safe presentation of the data. This position of the vessel is presented on the display of the Electronic Chart and Display Information System, abbreviated as ECDIS (Electronic Chart and Display Information System). If the right conditions are met, ECDIS can be an equivalent system to conventional nautical charts.

An indispensable part of the ECDIS system, in addition to the hardware and software parts, is the database part - that is the vector chart database ENC (Electronic Navigational Chart), which records information about each object on the chart.

The database encoding standard was designed in the 1980s as the hydrographic data standard S-57 (Transfer Standards for Digital Hydrographic Data). [1] It is now a widely used electronic ENC navigation data format. produced by hydrographic offices and manufactures for marine electronics distributors and customers. However, in recent years there are ongoing works to introduce an upgraded data format that will be technologically up-to-date and more structured. [2]

1.1 *Transition process and other data formats*

As a result of global implementation of ENC data, the development of technology, the growth of marine transport in recent decades and the description of the global geospatial data standard by ISO and OGC (Open Geospatial Consortium) the S-57 data standard is no longer actual state of knowledge. For this reason IHO plans to implement new data meta-standard S-100 (as the Universal Hydrographic Data Model) to support the next generation of hydrographic, navigation products and geographic systems. Based on the new S-100 format, on that layer ENC S-101 navigation data will be described. [3]

The new version of the standard is designed to manage the maritime space in a more efficient way, unlock potential of next-generation information, improve safety of marine environment, increase marine resources, improve position accuracy and provide more marine, dependent data. [4]

During data format transition, there is a need for secure data migration for maritime users and related organisations, especially during the transition period. As during any such format transition, the challenge is to ensure that both standards are supported simultaneously for a long period of time. This process will be continued until the IMO, IHO and other related organisations will set a final date for completion of the transition, marine electronic manufacturers will adapt to the new S-101 standard and equipment on convention ships that meets the requirements of the new format will be installed. In order to maintain a proper path for all manufacturers, the IHO regularly publishes updated specifications for the ENC product. [5]

In addition to the base S-101 other marine data will also be able to be linked on the basis of the new data model, such as: S-102 (bathymetric surface), S-103 (wave surface forecast), S-104 (tidal change surface), S-111 (current surface), S-122 (marine protected areas surface) and others.

However, still the most important element of the new standard will be S-101 navigation data, the provision of new, segregated data has the potential to provide a significant benefit to marine data users, especially if they will be grouped into one, common system. [6]

1.2 *Basics of Encoding and Data Modeling in ENC S-101*

Appropriate technological solutions will be used to upgrade and automate ENC databases in the new S-101 concept. The maritime navigation data will be based, among other things, on a more flexible, readable and structural XML data structure, the XML structuring language XML Schema (XSD), which defines data structures and validation rules, the UML (Unified Modeling Language), which models visual relationship between data, the GML (Geography Markup Language). which describes geography details and the metadata concept, which collect data about data.

XML (Extensible Markup Language) is a text format used to structure data. It's a universal tag language, which allows store and transfer big amount of data in simple and independent way. Using it data can be stored in separated files. [7] In XML tags (<...>) define structure and meaning of the data: they describe what certain data is.

Describing the structure and meaning of the data allows the data to be reused in different ways. One system will be enough to generate data and mark them with XML tags, and lately this data can be processed in any other systems, regardless of hardware platform or operating system. [8] To send, edit or display data sill will be needed appropriate software. Example of simple information contained in XML:

```
<note>
  <to>ECDIS users</to>
  <from>IHO</from>
  <heading>Reminder</heading>
  <body>S-101 will replace S-57</body>
</note>
```

XML Schema (also known as XSD - XML Schema Definition) is used to formally describe the structure of an XML document. XSD defines, which objects (features) and attributes can be placed in XML document, what type of data can be accepted, in what quantity and what relationships, constraints and order of occurrence exist between them. This allows different users to exchange data, where all users have agreed to the same data format. In essence XSD is a more sophisticated and more precise XML tool to increase data quality. [9] Example of verified information according to XSD:

```
<xs:element name="note">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="to" type="xs:string"/>
      <xs:element name="from" type="xs:string"/>
      <xs:element name="heading" type="xs:string"/>
      <xs:element name="body" type="xs:string"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

In this case, xs:element name="note" defines an element in the form of note - note.xml file. This element is type of complexType, which means it can have other elements. The expression xs:sequence means that complexType consists of a sequence of elements, and in place of xs:element name the information type type="xs:string" indicates that this base type can contain any text. [9]

When modelling a complex dataset, the graphical UML (Unified Modeling Language) will be helpful, as it allows to visualize and standardize the relationship, characteristics and behaviour between the different parts of navigation data in S-101. The UML diagrams allow the hierarchy and structure of the dataset to be illustrated. In addition, modelling the database by UML ensures that the data structure is readable, easy to understand and easy to implement by different users: maritime organizations, national hydrographic offices, navigation software developers or data users.

In addition UML enhances the process of documenting system components, allowing for a standardized method of storage. As a result all components can be represented in UML diagrams and can easily be interpreted.[10]

In the S-101 standard, using UML, the relationships between components will be described using several types of association. The first of these is the feature association, which describes a simple connection between two objects, e.g. a CautionArea is associated with an ArchipelagicSeaLane by using CautionAreaAsssociation. The use of the role +consistsOf indicates that the superior object consists of parts, and +componentOf that the object is part of another object, but still as an individual, independent element. The Multiplicity of attributes used here indicates how many times an element can occur in a given context of ENC data. The description 0..* means that an element may not occur at all or can occur infinitely many times.

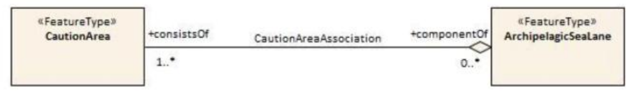

Figure 1. Feature association Source: IHO ENC Product Specification S-101 Edition 1.1.0.20221208 – Xxxx 2022 [12]

Another type of relationship is aggregation, occurring between two or more types of objects, where a class may consist of parts, but these parts may exist independently of the whole. In this case an IslandGroup may consist of multiple LandArea, and it is described by IslandAggregation. However, these sub-components (areas) may exist independently of the superior aggregate (group of islands). In this situation, +compomentOf multiplicity 0..1 indicates that it may not be used or may be used only once.

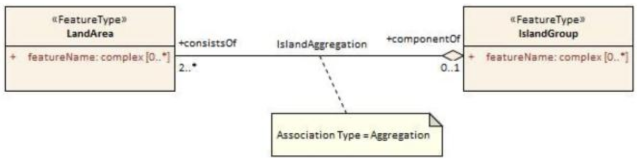

Figure 2. Aggregation relationship Source: IHO ENC Product Specification S-101 Edition 1.1.0.20221208 – Xxxx 2022 [12]

The last type of relationship used in S-101 UML is composition, a stronger form of aggregation described in example below as StructureEquipment. In this situation, the parts cannot exist separately of each other, and if the whole is removed, the individual parts will also disappear. An example of this can be the navigation buoy (as the parent object marked with black rhombus). If it is removed, all subordinate parts like the fog or light characteristics will also be permanently deleted. [12]

Figure 3. Composition relationship Source: IHO ENC Product Specification S-101 Edition 1.1.0.20221208 – Xxxx 2022 [12]

The S-101 will also use the GML (Geography Markup Language) to describe physical, maritime navigation data. GML is closely related to XML, and it is used to model geographic spatial data such as position of object on a chart, their topology or geometry. GML is also an ISO standard: ISO 19136:2007. [11] When using GML, it is important to have an appropriate spatial reference system as here is used CRS (Coordinate Reference System), which defines how geographical coordinates are related to actual locations on Earth. In GML, the spatial reference system is usually described using the CRS identifier, which is included in the srsName by EPSG:4326 value - this indicates the commonly used and well-known geodetic system WGS-84.

In the S-101 ENC standard, the main geometries used to describe physical maritime data are:

– point - for single, zero-dimensional locations e.g. coordinates of a navigational buoy,
– curve - for one-dimensional, linear objects, consisting of a group of points e.g. coastline,
– surface - for two-dimensional area objects, where surface boundaries are defined by curves e.g. bay area of a specified depth.

With the huge amount of hydrographic and navigational data produced by hydrographic offices necessary, one of the key elements with the S-101 is the metadata concept - the collection of data about data.

Knowledge about data quality, age, method of obtaining data and their proper segregation is a key to appropriate application, as different systems and different receivers could have different quality requirements. It is why during S-57 to S-101 transition data producers can add or edit information about quality and characteristics of single data. In the future it can help during searching and proper segregation data. Examples of used metadata can be information about the responsible institution and country for a particular area cell or information of dates of specific data e.g. date of depth measurement. [12]

1.3 *Process of encoding ENC data*

During data migration there is a real risk that some information may be corrupted or lost, it is a fear that some users may experience during the transit and implementation of new format. In order to maintain data integrity for users, the data encoding process have to take place at a certain pace, with the highest security standards and maintaining the required data quality.

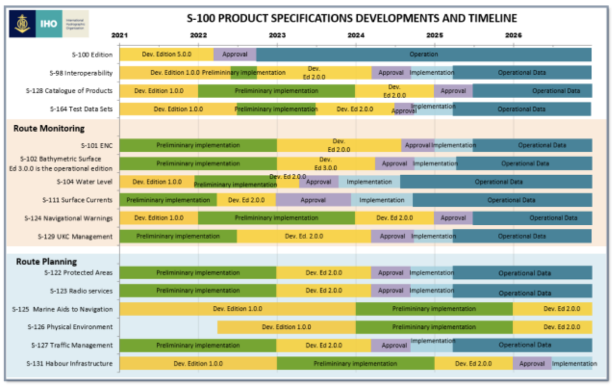

Figure 4. Planned timeline for IHO tests and implementation for S-100 models SOURCE: IHO Roadmap for the S-100 Implementation Decade (2020 – 2030), Annex 2 S-100 Timelines

As of now (status according to IHO documents of 12 July 2022) data in S-101 format is not expected to be implemented widely until 2026. This phase is of course followed by a multi-year period of research and testing. [13]

In order to maintain proper organisation and to automate the process of data presentation, two data catalogues are distinguished: Feature Catalogue and Portrayal Catalogue. In the S-57 standard, the description of encoding data is contained in separate documentation IHO S-57 Appendix A, Object Catalogue.

The Feature Catalogue is a basic document that contains a detailed description of all available objects, attributes, attribute value, relationship and roles in the S-101 ENC data format. This catalogue is available as an XML document meeting the S-100 XML Feature Catalogue Schema standards.

The second Portrayal Catalogue describes the system mechanism for displaying the information found in the ENC database. This catalogue contains a set of data visualization rules, a set of symbols, line styles, area fills, fonts and colour profiles. The Portrayal Catalogue is a document, which is described as an XML file, however separated specified rules are described in Lua Script format.

The IHO's new data format uses a concept of class as a classification of a set of objects that share the same attributes, methods, relationships and operations e.g.a class of lighthouse. For further description, the IHO uses two basic data types: features as a physical objects and representation of the real world e.g. lighthouse and attributes as characteristic describing the directly linked object e.g. the light elevation of lighthouse. In the case of attributes, they are described by a data type, where it is a specification of a value domain with permitted operations on value in that domain. The data type is identified by the given term:
- Integer, without decimals
- Real, floating point number e.g. depths,
- Boolean e.g. presence or absence of a particular object,
- String e.g. short description of the area,
- DirectPosition e.g. via set of geographic coordinates,
- Date.

In order to permanently and uniquely identify the related object, the Identifier will be used as a linguistically independent string e.g. light elevation of lighthouse - 121. The necessary units of meters will be described in the attribute description, this will be discussed later in the article. In the case of encoding and selecting the appropriate attribute, which have a fine set of predefined values e.g. the colour characteristics of the light the Enumeration, will be used, where attributes can only take values from a given list. [12]

2 METHOD AND MATERIALS USED

In this article, a comparative analysis of the benefits to be gained from the S-101 format is carried out. For this purpose, the information needed to encode and describe ENC navigation data was examined using IHO specifications:
- for S-57: IHO S-57 Appendix B.1: ENC Product Specification Annex A: Use of the Object Catalogue for ENC Ed 4.3.0 and IHO S-52 Annex A: IHO ECDIS Presentation Library Edition 4.0(.3),
- for S-101: IHO S-101 Feature Catalogue Ed 2.0.0 and IHO S-101 Portrayal Catalogue Ed 2.0.0 from GitHub repository.

3 COMPARISON OF DEPTH PARAMETER CODING IN S-57 AND S-101

In a navigational context, one of the most important parameters of ENC data is depth. It is first surveyed, then encoded and finally it is displayed to viewers in ECDIS systems. The basic information and principles needed to be described and code it in both formats are analysed below.

In the current S-57 standard, a geo-object such as a depth area, closed linearly, is described by the DEPARE attribute. For each such spatial area with given geo-coordinates, which will take the shape of a polygon on the chart a maximum and minimum boundary depth must be encoded using the attribute DRVAL1 (Depth Range Value 1) and DRVAL2 (Depth Range Value 2). Below in Figure 5. area 1 is coded as DRVAL1=0, DRVAL2=5. The corresponding colour layer will also be assigned to these areas using the DEPCNT (DepthContour). In the S-57, the format used is a closed, binary IHO format, which contains a number of numeric values and record references in the form of a byte string, but it is not directly readable by the viewer. [14]

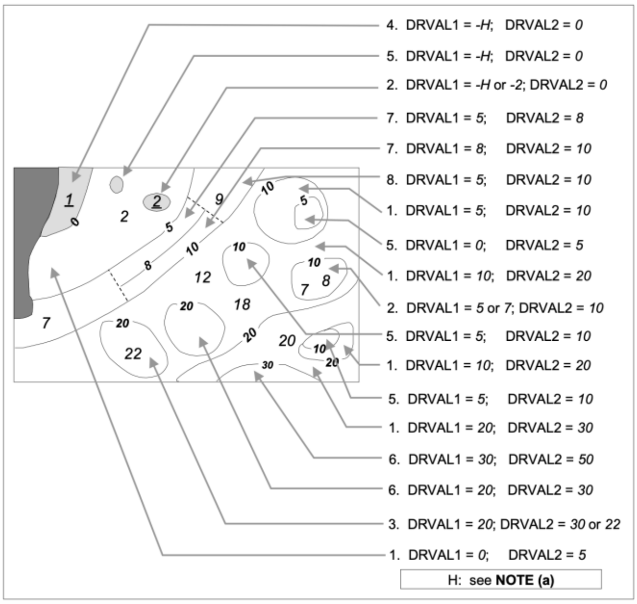

Figure 5 Areas of different depths coded with DRVAL1, DRVAL2 parameters. Source: IHO S-57 Appendix B.1: ENC Product Specification Annex A: Use of the Object Catalogue for ENC Ed 4.3.0 – October 2022

Currently, the display of information on an ECDIS system is defined through a set of rigid rules described in IHO S-52 Annex A: Presentation Library. This is a simple graphical library that technically describes how individual objects should be presented on the chart e.g. specific colour, width, shape of depth metric values. In this version there are static rules for displaying information adopted according to a uniform pattern, where each symbol is assigned to characteristics, regardless of context. [15]

In the S-101 standard, the format used for encoding dataset files will be still binary (.000), however the 'environment' needed to describe and create rules for depth area parameter will be defined now by DepthArea as a unique identifier in the attached Feature Catalogue, in XML file

(CATALOG.XML). It will allow creating hierarchy, agenda and helps automatize specifications. As well as DEPARE as an alias in the form of additional alternative name combining both standards. Sometimes DEPARE3 can be also found in particular working documentation. [17]

In the Feature Catalogue there is defined name of the described area under <S100FC:name>DepthArea</S100FC:name>, as well as an IHO definition under <S100FC:definition>. Minimal and maximum depth will be now described by depthRangeMinimumValue and depthRangeMaximumValue with the multiplicity set to 1…1 meaning that for maximum and minimum value must occur exactly once.

In addition to this information, the type of object is automatically defined by <S100FC:featureUseType>geographic</S100FC:featureUseType>). It means that the object is geographical and refers to a specific location on the chart. The geometry of the object is also described by g<S100FC:permittedPrimitives>surface</S100FC:permittedPrimitives> — the object is represented as a surface, which is the area of a specific polygon on the chart.

An additional advantage in the S-101 standard is the interoperability attribute in a multidisciplinary context which allows data exchange and future integration between standards based on S-101 model. The records <S100FC:attribute ref="interoperabilityIdentifier" /> indicates that an object has an interoperability attribute associated with it. The attribute <S100FC:attributeBinding sequential="false"> indicates that sequential occurrence of this attribute is not required and its presence is not needed in every object. This type of annotation allows more flexibility by enabling this attribute to be assigned only when required. [16]

In the Feature Catalogue the units of meters will be automatically defined by the uom parameter (units of measurement), and the assigned unit can be found for the object. For example, for depthRangeMinimumValue and depthRangeMaximumValue will be described as:

```
<S100FC:uom>
  <S100Base:name>metre</S100Base:name>
  <S100Base:symbol>m</S100Base:symbol>
</S100FC:uom>
```

In the S-101 standard, encoded navigation data will be displayed by automatically defined rules described in Portrayal Catalogue, where symbolization is not statically assigned to an object. This catalogue is more flexible, giving the possibility to display data in a dynamic way adapted to the context, condition or display devices. With this solutions e.g. buoys or obstacles can be displayed more clearly when these are in vicinity. For users, it is important that there will still be a uniform symbology for all ECDIS systems that will support the S-101 format. Another advantage of Portrayal Catalogue compared to Presentation Library is its modularity. It allows the catalogue to be updated and developed without major changes in S-101 standard itself - so the display rules can be changed without modifying the ENC whole data structure, making it more future-proof.

In the Portrayal Catalogue you will find a breakdown of the Rules for displaying specific parameters e.g.. DEPARE03 in the depth context. The script is written in Lua and you can find call of the depth object by automatically capturing information about the object, its display properties, context parameters and the viewing group, which is to define in which layer and which visibility the object is to be presented: function DEPARE03 (feature, featurePortrayal, contextParameters, viewingGroup). The maximum and minimum depth should be then retrieved via the code: local depthRangeMinimumValue = feature.depthRangeMinimumValue. The SEABED1 function is then called, which refers to the correct symbolisation of the area depending on the depth by giving the layers appropriate colouring. In addition to those above script checks whether the area is dredged, whether there are constraints, objects as depth contour, land area of harbour in the context of verifying the safety of navigation. In addition, it also will check the quality of the data by drawing the appropriate line, whether it analyses the SafetyContour or RadarOverlay activity. These are only some of the possibilities for displaying depth data on ENC charts in S-101 format by Portrayal Catalogue. [17]

Analyzed code fragment from Feature Catalogue Ed 2.0.0 (accessed on 17.10.24 via GitHub repository) for DepthArea parameter:

```
<S100FC:S100_FC_FeatureType>
  <S100FC:S100_FC_FeatureType isAbstract="false">
  <S100FC:name>Depth Area</S100FC:name>
  <S100FC:definition>A water area whose depth is within a defined range of values.</S100FC:definition>
  <S100FC:code>DepthArea</S100FC:code>
  <S100FC:alias>DEPARE</S100FC:alias>
  <S100FC:definitionReference>
  <S100FC:sourceIdentifier>262</S100FC:sourceIdentifier>
  <S100FC:definitionSource ref="IHOREG" />
  </S100FC:definitionReference>
  <S100FC:attributeBinding sequential="false">
    <S100FC:multiplicity>
      <S100Base:lower>1</S100Base:lower>
      <S100Base:upper xsi:nil="false" infinite="false">1</S100Base:upper>
    </S100FC:multiplicity>
    <S100FC:attribute ref="depthRangeMinimumValue" />
  </S100FC:attributeBinding>
```

```xml
  <S100FC:attributeBinding sequential="false">
    <S100FC:multiplicity>
      <S100Base:lower>1</S100Base:lower>
      <S100Base:upper xsi:nil="false" infinite="false">1</S100Base:upper>
    </S100FC:multiplicity>
    <S100FC:attribute ref="depthRangeMaximumValue" />
  </S100FC:attributeBinding>
  <S100FC:attributeBinding sequential="false">
    <S100FC:multiplicity>
      <S100Base:lower>0</S100Base:lower>
      <S100Base:upper xsi:nil="false" infinite="false">1</S100Base:upper>
    </S100FC:multiplicity>
    <S100FC:attributeVisibility>privateVisibility</S100FC:attributeVisibility>
    <S100FC:attribute ref="interoperabilityIdentifier" />
  </S100FC:attributeBinding>
  <S100FC:attributeBinding sequential="false">
    <S100FC:multiplicity>
      <S100Base:lower>0</S100Base:lower>
      <S100Base:upper xsi:nil="true" infinite="true" />
    </S100FC:multiplicity>
    <S100FC:attribute ref="information" />
  </S100FC:attributeBinding>
  <S100FC:informationBinding roleType="association">
    <S100FC:multiplicity>
      <S100Base:lower>0</S100Base:lower>
      <S100Base:upper xsi:nil="false" infinite="false">1</S100Base:upper>
    </S100FC:multiplicity>
    <S100FC:association ref="AdditionalInformation" />
    <S100FC:role ref="theInformation" />
    <S100FC:informationType ref="NauticalInformation" />
  </S100FC:informationBinding>
  <S100FC:featureUseType>geographic</S100FC:featureUseType>
  <S100FC:featureBinding roleType="association">
    <S100FC:multiplicity>
      <S100Base:lower>0</S100Base:lower>
      <S100Base:upper xsi:nil="true" infinite="true" />
    </S100FC:multiplicity>
    <S100FC:association ref="UpdatedInformation" />
    <S100FC:role ref="theUpdate" />
    <S100FC:featureType ref="UpdateInformation" />
  </S100FC:featureBinding>
  <S100FC:permittedPrimitives>surface</S100FC:permittedPrimitives>
</S100FC:S100_FC_FeatureType>
```


4 DISCUSSION

This section of the article presents the results of the comparative analysis carried out and the detected technological advantages of the new S-101 format to discuss.

4.1 *Main objectives of S-101 and differences from S-57*

The S-101 data standard proposed by IHO is expected to provide a number of developments in field of technology and functionality compared to the older S-57 version. In addition to the mentioned interoperability with other maritime data, greater functionality and data integrity this format and database is expected to be, above all, better organised and managed with modern data formats and future applications.

The S-57 data model was based on a rigid data model, now the data and important specifications will be able to be described in a more flexible way. The support architecture of new format is designed with modern ECDIS system in mind, which will require more advance feature, integrity and clearer display. The S-57 standard is currently outdated to the new technologies being introduced and more prone to errors.

Another advantage of the S-101 standard is that it is ‘future-proof’, allowing for easier implementation of necessary extensions and updates. S-57 is time-consuming and difficult to adapt and modify today. S-101 is also intended to be a format that can eliminate the main disadvantage of ECDIS, namely the unreadability of data during voyage and the overload of information on electronic charts. In the new standard, characters and layers will be able to be presented more dynamically, therefore chart readability and navigation safety. Time-limited data is also planned to be introduced in the future, the S-57 format was not able to provide this possibility.

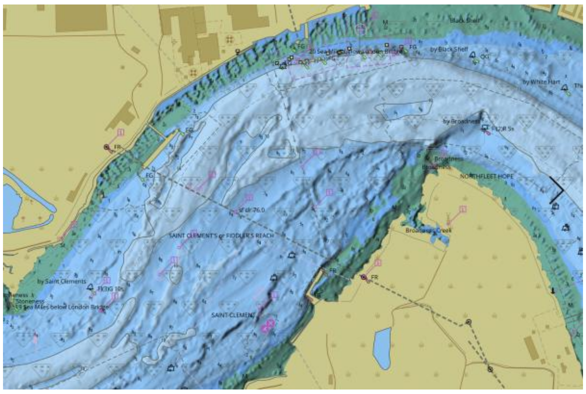

Figure 6. S-101 in combination with S-102 bathymetric grid Source: https://www.navtor.com/post/the-101-on-s-100-what-you-need-to-know-about-maritime-s-big-data-transformation

A good example of interoperability of data possible with the S-101 format will be data that could be presented in 3D. In the S-57 version, they could be only presented two-dimensionally. Now in 3D format seabed data will allow users to gain a better insight into the bottom shape of given area. The 3D bathymetric models will allow safe draught planning and more efficient sea-route planning. Data on quays, bridges, underwater wrecks, landforms around islands, reefs and underwater wrecks can also be presented in this form, enabling safer assessment of the situation, evaluation of distances and detection of potential obstacles to avoid danger. By using the new data format, it is also possible to design dynamic models for changes in bathymetry due to currents, material deposition and changes in water layers. [19]

Other benefits of the new format include increased precision of the described and displayed data through the use of validation tools and more beneficial handling of large sets of informations by describing the data using catalogues: Feature Catalogue and Portrayal Catalogue, which will allow automatic reading of the data, flexible updating of the catalogues and proper grouping by the computer system. In comparison, the S-57 is unfortunately limited, where the data are placed as separate, individual parts. [14]

Table 1. Summary comparison of the advantages and disadvantages of the S-57 and S-101 format

S-57	S-101
no integrity with other dependent data	interoperability with other data, increased functionality
technologically outdated, difficult to update	technologically up-to-date, easier to update
rigid data model	flexible data model
two-dimensionality of informations	three-dimensionality of informations
limited precision	increased precision
lack of automatic data validation	modern automatic data validation tools
data overload, illegibility	possibility of data presentation in a more readable way
no possibility to include temporal and dynamic information	possibility to include temporal and dynamic information
separate, individual parts of the database, difficult to read	automatic data reading

5 CONCLUSION

The transition from the S-57 standard to S-101 version is currently one of the key challenges for authorities responsible for implementation and maintenance of ENC data, as well as maritime safety authorities. This process has a huge impact on data management, navigation systems, their users worldwide and the technology needs to be updated significantly to avoid risks to ships, crews and the marine environment.

The new S-101 format has many benefits for maritime users and its implementation should not be significantly delayed. One of the most important advantages is its technological updateness, flexibility, future-proofing and use in the future ECDIS systems, which can eliminate the lack of clarity of electronic charts and increase safety of navigation by providing a more reliable description of reality.

The database will be built in a more flexible way and all data will be described, grouped and characterized, which will also bring an increase in the quality of navigation data. The technology used in S-101 based on data validation specification, attached automated catalogues, rules for describing and displaying objects make the S-101 standard a promising format and necessary soon to implement for marine data users.

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[15] IHO S-52 Annex A: IHO ECDIS Presentation Library Edition 4.0(.3) – October 2014 (With Clarifications up to December 2020) Catalogue for ENC Ed 4.3.0 – October 2022
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