Application of geodatabase dedicated for bathymetric data during the production of electronic navigational charts for inland shipping

Marta Włodarczyk-Sielicka, Izabela Bodus-Olkowska, Andrzej Stateczny

Maritime University of Szczecin, Faculty of Navigation, Chair of Geoinformatics
71-250 Szczecin, ul. Żołnierska 46, e-mail: {m.wlodarczyk; i.olkowska; a.stateczny@am.szczecin.pl}

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Abstract

Digital hydrographic products include the ENC Electronic Navigational Charts and the IENC Inland Electronic Navigational Charts used for inland shipping. The process of IENC production comprises data acquisition and editing. Each object belongs to a class specified in the applicable standards and possesses necessary attributes. IENC cells include, among others, data related to depths in a given water body. Contemporary bathymetric measuring systems allow for saving more and more data of increased quality. Examples of systems characterized by the ability to acquisition high density data are interferometer systems. The authors of this article used GeoSwath Plus 250 kHz sonar system to collect bathymetric data. Bathymetric data included in the IENC cell should be up to date, structured and easy to manage. A piece of software by the ESRI Company, also dedicated to creating hydrographic products, allows to do just that. The authors have used a specialized geodatabase during the IENC production, which made managing bathymetric data easier. The article describes an analysis of the geodatabase's functionality during the production of electronic navigational chart for inland shipping.

Introduction

Electronic navigational charts mostly reflect the content of paper navigational charts. They include detailed description of hydrographic objects and navigational obstructions, and are used as the basic information source for the navigator who uses the ECDIS (*Electronic Chart Display and Information System*). They allow the navigator to, for example, gain quick access to a desired information, assess the situation based on the present position of their own vessel or control the water under-keel clearance through the presented depths [1]. Inland electronic navigational charts are a major source of navigational information for safety reasons in inland waterway transport. Important information included in electronic maps is, apart from the shoreline or hydraulic engineering structures, is the depth and any underwater objects. This data should be up to date and periodically or dynamically updated, because of the changeable nature of inland waters. In the countries that use rivers as the main means of

goods' transportation, electronic navigational charts are an imperative tool used for safe navigation. The IENC charts are included in the ECDIS system, meet the requirements of the S-57 and S-52 standards, and the data displayed on the charts should be acquired with accuracy surpassing the S-44 standard for the special class.

The area obliged to implement the RIS system extends from Szczecin to Ognica (over 97 km) and for this area IENC charts will be designed for. At the time of writing this article, there are no authorized electronic chart cells for the inland areas of Poland. The software used in this paper, dedicated for designing the geodatabase for bathymetric data of inland charts, was one of the ESRI Company – ArcGIS for Maritime: Bathymetry in which the basic program functions were extended by management processes and pooling of resources of bathymetric data and its metadata. The software allows for an easy and clear management of bathymetric data by means of the BIS (*Bathymetric Information System*) central geodatabase, as well as

includes tools intended for gathering and generating bathymetric areas used in the subsequent process of IENC chart production.

Bathymetric Data Acquisition

The technology for acquiring bathymetric data necessary in the process of electronic inland navigational charts production mainly depends on the kind of water body, its size and local characteristics. Poor water transparency, long periods of foliage blooming exclude the possibility of using measurement methods based on light waves. The optimal solution, although not devoid of errors, for depth measurement in such water bodies seems to be the use of underwater acoustics. A shallow, muddy bed will cause significant sound absorption which in turn will lead to large inconsistencies in depth measurement. Another factor is the dynamic change of water state, which is directly proportional to the frequency of considering corrections using the gauge indications. Moreover, bathymetric data becomes outdated almost immediately due to water movement of gathering of bed material. During severe hydro-meteorological phenomena, the daily difference in water levels might even amount to several dozens of centimetres. Furthermore, the number of water gauges and their distribution are not always adequate to the needs of precise bathymetric measurements.

Depth measurements based on sound propagation is possible by means of singlebeam echosounders, multitransducer echosounders and multibeam echosounders, as well as based on interferometric systems. Using singlebeam echosounders, data density is in many cases insufficient for accurate reproduction of digital model of the seabed. A chart constructed in this way does not reflect the precise characteristics of the seabed, just its highly approximate shape. Multibeam sounders and interferometric sonar systems allow to produce resolutions of a few (transverse resolution) by a few dozen (longitudinal resolution) centimetres, depending on the transducer frequency and speed of the unit during the acquisition. Still, interferometer systems, due to their operational characteristics, have significant advantage over multibeam sounders in terms of shallow water measurements. Table 1 depicts a comparison of systems: singlebeam, multibeam and interferometric in terms of seabed coverage with data.

Currently, there are no existing standards of hydrographic measurements for inland water areas in Poland. Hydrographers thus rely on international provisions of the S-44 Standard for Hydrographic Surveys, developed by the IHO (*International*

Table 1. Comparison of operational parameters of bathymetric measuring systems (own research – developed on the basis of [2, 3, 4])

Parameter	EA400 (single beam)	EM3002 (multi-beam)	GeoSwath Plus (interfero-metric)
Operational frequency	38 / 210 kHz	300 kHz	250 kHz
Viewing angle	13 / 7°	200°	240°
Maximum coverage (footprint) for depth = 10 m calculated for depth 10 m	2.2 m / 1.2 m	8 × depth 80 m	12 × depth 120 m
Depth resolution	5 / 1cm	1 cm	0.3 cm

Hydrographic Organization). The present, fifth edition of that publication was published in February 2008. The S-44 Standard defines the basic methods of hydrographic measurements and classification of water bodies by the precision requirements for hydrographic operations carried out on them. It also includes detailed methodology of assessment of depth and position measurement accuracy during operation. The standard also comprises guidelines for measurement data control and development, as well as storage in dedicated databases. Because of production the electronic chart for inland shipping and the present lack of existing regulations relating to the accuracy of hydrographic data acquisition in those water bodies, hydrographers carry out measurements in accordance of the provisions of the S-44 standard's special class. The requirements for depth measurements accuracy can be found in table 2.

Table 2. Minimal requirements for bathymetric measurements accuracy according to the IHO S44 standard [5]

Order	Special
Description of the area	Areas where under-keel clearance is critical
Maximum allowable THU[*]	2 m
Maximum allowable TVU[**]	$\pm\sqrt{a^2+(b\times d)^2}$ $a = 0.25$ m $b = 0.0075$ m

[*] Total horizontal uncertainty at the position of the sounding, at the 95% confidence level
[**] Total vertical uncertainty of the reduced depths, at the 95% confidence level

For the purpose of conducting the research, the GeoSwath Plus interferometric system has been used, which is a part of the hydrographic equipment of the research vessel Hydrograf XXI, owned by the Maritime University of Szczecin. The acoustic signal generated by that system is reminiscent of the side sonar impulse – azimuthally narrow far-reaching perpendicularly to the direction of vessel's

movement. The beam range swath exceeds 240 degrees. While the vessel moving over the profile, the transducer mounted on the hull moves, generating a profile of single lines forming swath (Fig. 1) corresponding to the imaged surface of the seabed.
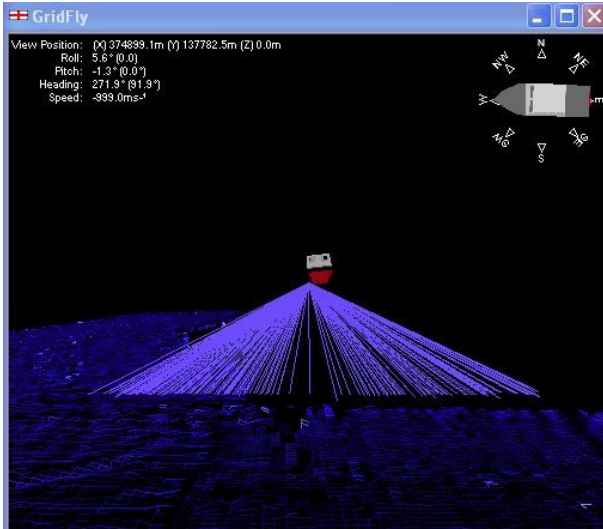

Fig. 1. Visualization of data coverage during the acquisition by means of bathymetric interferometric system [screen of Gridfly window, GS+ ver 3.50r software]

The difference between the sonar bathymetric system and the side-scan sonar is the acoustic energy record – in case of an interferometric system, the difference of the reflected signal's phase is used to determine the depth, and the large number of sensors in close proximity to each other ensures high density and precision of the measurement.

IENC

Designed electronic charts for inland shipping should be based on specified standards. Those standards can be divided into five main sections and their attachments (Fig. 2). Moreover, IENC charts should comply with convention SOLAS (*Safety Of Life At Sea*) set under the IMO (*International Maritime Organization*).

The standard for electronic navigational charts for inland shipping is mainly based on the marine standard S-57 with all attachments and appendices, which involves the use of identical theoretical model and the same data structure [7]. The S-57 required modification due to the need of IENC charts to visualize objects and data used solely in inland navigation, not taken into account within maritime areas. According to the group dealing with standardization of electronic chart cell (Inland ENC Harmonization Group), it is recommended that Inland SENC (*System Electronic Navigational Chart*) includes all the necessary information related to safe navigation. It may also contain additional information that will be helpful during navigation, like layers related to bathymetry [8]:

− Depths in Fairways and Areas:
  • Detailed Depth – referenced to one water level;
  • Detailed Depth – water level model;
  • Dredged Area;
  • Fairway;
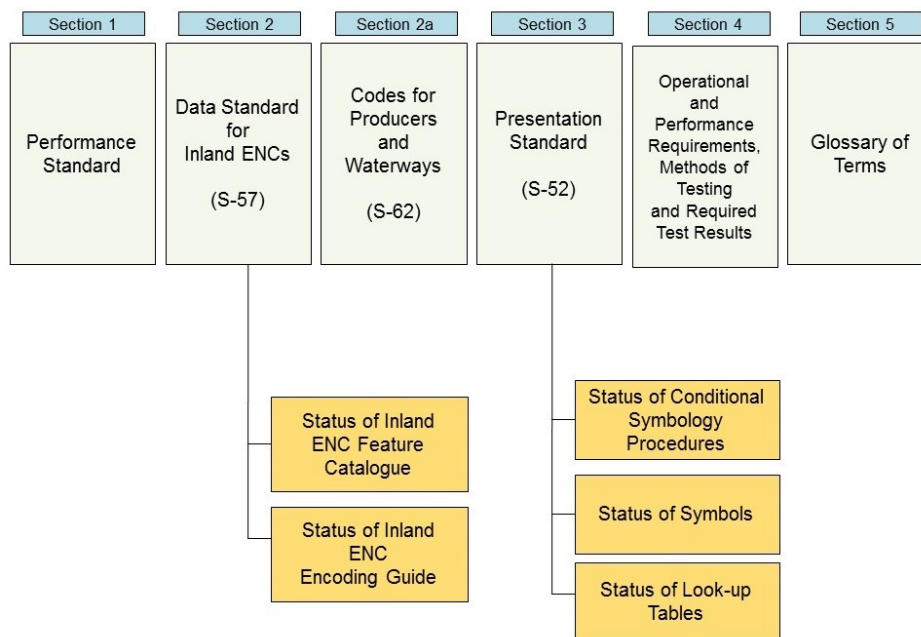 • Fairway Depth / Project Depth;

Fig. 2. The general scheme of existing standards for Inland ECDIS (own research – developed on the basis of [6])

- Low / High Water Range (Drying Height);
- Shallow Depth;
- Soundings;
- Unsurveyed Area;
− Depth Contours;
− Depth References:
  - Depth Indicator;
  - High Water Mark;
  - Vertical Clearance Indicator;
  - Waterway Gauge;
  - Waterway Profile.

Application of geodatabase dedicated for bathymetric data

The charts have been developed by means of ArcGIS Desktop software, in line with the accepted methodology of creation the GIS (*Geographic Information System). Application* ArcGIS for Maritime: Bathymetry has also been used, it extends the possibilities of ArcGIS for Desktop by processes of managing and combine of vast amounts of post-processed bathymetric data and its metadata. This products allows managing of bathymetric data with the central geodatabase referred to as BIS (*Bathymetric Information System*). It includes tools intended for storing and generating bathymetric surface models. The bathymetric data can be stored locally or on a shared network drive. The developed surface models are used during creation of electronic navigational charts for inland shipping. Moreover, they can be used as a source for development of 3D points and for specialized spatial analyses. ArcMap application was mainly used for data compilation.

Compilation of such a diverse and large amount of data required the use of the BIS geodatabase which is dedicated for bathymetric data. BIS is a geodatabase related to data stored on local or shared geodatabases. One if its key features is that the bathymetric data is not loaded directly into the geodatabase, so the required amount of data storage memory is diminished by avoiding duplication of source data. The advantage of a geodatabase is the possibility to determine a spatial reference, which uniforms, in particular, the used coordinate system and the scope of development. The default geographic system is WGS 84. It might turn out that the used bathymetric data are better managed by means of several BIS geodatabases. Bathymetric data used in the article have been collected with the GeoSwath Plus 250 kHz interferometric system which is a part of the hydrographic equipment of the research vessel Hydrograf XXI, in the area of the West Oder. Next, it has been processed using

GS+ software and converted to BAG format with Caris HIPS and SIPS 7.1 software. The used software supports only bathymetric data in BAG (*Bathymetric Attributed Grid*) format. BAG is a kind of bathymetric data format that complies with the standards developed by the Open Navigation Surface Working Group [9].

During creation of a new geodatabase for bathymetric data, an existing geodatabase should be indicated where the new BIS scheme is going to be uploaded. One can simultaneously indicate the location of copies of all the data added to the geodatabase, location of the Overviews and location of metadata settings. During operation of several BIS geodatabases, they can be managed by means of only one window. When renaming a geodatabase or removing it, the changes occur only on the list in the management window. The geodatabase's proper name will not be changed or removed from the hard drive, which provides an additional protection of the bathymetric data. During the work with geodatabase, it is possible to automatically diagnose possible problems. A tool locates the problem, determines its kind and indicates whether it is going to be fixed automatically or it requires manual intervention.

An important element of a geodatabase is metadata related to bathymetric data. There are three kinds of metadata: Collection, Internal and Extended. Collection metadata defines the attributes necessary for a collection and can describe bathymetric data located in a common geographic area, data acquired during a surveyor other logically grouping of dataset. Internal metadata forms fields of internal metadata for bathymetric dataset. Extended metadata is additional metadata not included in the internal metadata. Default Extended metadata contains: classed of measurements, sensors, types of measurements and types of vessels. They can be adjusted accordingly or replaced with others. For example, one can add fields that define the kind of echosounder used during acquisition of data. Collection and Extended metadata fields and their related drop-down lists are fully configurable in XML files. For Internal metadata, there are strict limits related to the possibilities of its edition. It has to consistent with the existing standards for dataset registered in the BIS geodatabase. Internal metadata for BAG data must be consistent with the ISO 19115 standard [9].

Bathymetric data comprise of large sets that need to be organized properly. Geodatabase allows using descriptive data and merges specific data into collections, which makes it easier to organize and manage data. During the creation of a new collec-

tion, one should indicate metadata that will determine all the data contained in it. Default Collection metadata includes status, description, contact organization, contact person, start date, end date and classification.

While data is being added to the geodatabase, a connection is established between datasets in BAG format and the geodatabase. The geodatabase stores and track the location of each dataset in tables while the data remain at their physical locations. There is a possibility to connect to many BAG datasets in many different storage locations. One can add data directly to the geodatabase or to a predetermined collection. The previously created metadata (Extended and Collection) is allocated. The bathymetric data is merged into mosaic datasets, pyramids are created and statistics are calculated for the purpose of faster rendering. Boundary for the mosaic datasets are automatically created and the percentage of data coverage is calculated. During addition of the data to the geodatabase, BDI (*Bathymetric Data Index*) is automatically created. It is a catalog of all bathymetric data, managed by mosaic dataset within a geodatabase, which contains the list of all the areas registered in BIS. Figure 3 presents BDI and limits for all individual datasets, acquired during addition of bathymetric data to the geodatabase.

Fig. 3. Bathymetric Data Index and boundaries for each datasets [own research]

Next, in order to perform data sets selection, metadata filters can be used for an active geodatabase. There is a possibility to create specific sorting rules (based on metadata fields) which will deter-

mine the displaying order of datasets, creating a composite surface. When the data is properly sorted, an overview of the mosaic datasets can be generated. The next stage includes saving the composite surface as a surface model (Fig. 4). A surface model always includes predetermined sorting rules and specific bathymetric datasets.
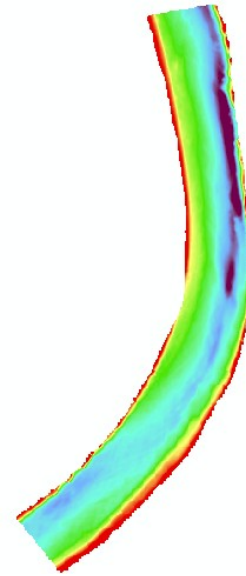

Fig. 4. Surface model [own research]

If the option of creating a mosaic dataset is selected, one can choose to build Overviews for it, meaning lower-resolution images. Overviews are displayed during reviewing of the composite surface. When zoom in, the application renders levels of finer resolution. The most appropriate overview is chosen based on the display scale. Use of them increases the displaying speed and reduces CPU usage. The created surface model is never permanently deleted from the geodatabase. Figure 5 depicts the structure of created geodatabase.
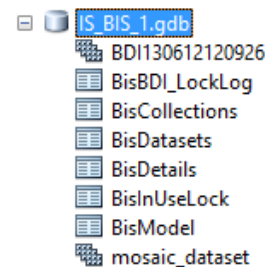

Fig. 5. Geodatabase structure [own research]

The generated bathymetric surface model can be used during the creation of an electronic navigational chart for inland shipping. One can extract depth from the surface model, in the form of points at predetermined spaces and export them to an ASCII file. This data can be used during the creation of the IENC.

Fig. 6. IENC for area of the West Oder [own research]

Conclusions

The paper presents the use of a geodatabase dedicated for post-processed bathymetric data to produce electronic navigational charts for inland shipping. Because of its functionality, it can be used to easily organize, access and use large datasets and their metadata. There is a possibility to use metadata for quickly searching out data that meet specified criteria. A geodatabase makes it possible to create collections of bathymetric datasets and manage them. One can create specified sorting rules (based on metadata fields) which will determine the order of dataset displaying, creating a composite surface. This surface forms the basis for creation of a bathymetric surface model. A geodatabase manages surface models stored in it, which can then be used during creation of electronic navigational charts for inland shipping. Moreover, they can be used as a source for creating 3D points and for specialized spatial analyses, helpful in decision-making and analytical processes.

In connection with the idea of geodatabase, it is created for a user who should have basic informatics knowledge. Using the geodatabase is intuitive and problem-free. Because of the fact that the universal format of bathymetric data is ASCII, the major defect of a geodatabase is the impossibility of uploading data in formats other than BAG into it. Using a geodatabase dedicated for bathymetric data allows reducing the required data storage needs by not duplicating source data. There is a possibility to display all bathymetric datasets, at the same time, in a single view. Moreover, using Overviews increases the displaying speed and reduces the CPU usage.

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