Igor KARNIČNIK*
Institute of Geodesy
Jamova 2, SI-1000 Ljubljana, Slovenia
Jelenko ŠVETAK
University of Ljubljana, Faculty of Maritime Studies and Transportation
Pot pomorščakov 4, SI-6320 Portorož, Slovenia
*Corresponding author. E-mail: igor.karnicnik@geod-is.si

ANALYSIS OF ELECTRONIC NAVIGATIONAL CHARTS IN ORDER TO ENHANCE THE SAFETY OF NAVIGATION

Summary. Navigational charts were, are and will probably be the most important aid to navigation on the ship's bridge. Paper charts have already been used for decades and now electronic ones are joined with the help of modern computer technology. The paper presents different types of navigational charts, electronic charts systems, their importance for safety of navigation, and the type of charts navigators can or should carry on board their ships.

ANALIZA ELEKTRONICZNYCH MAP NAWIGACYJNYCH W CELU POPRAWY BEZPIECZEŃSTWA NAWIGACJI

Streszczenie. Mapy nawigacyjne są i zawsze będą najważniejszym źródłem pomocy w nawigacji na mostku kapitańskim. Papierowe mapy nawigacyjne były używane przez wiele dekad, a obecnie elektroniczne formy nawigacyjnych map są wprowadzane z pomocą nowoczesnych technologii komputerowych. Artykuł prezentuje różne typy map nawigacyjnych, elektroniczne systemy map, rolę, którą pełnią dla bezpieczeństwa nawigacji oraz typy map, które powinny być używane i zabierane na pokład statków przez nawigujących.

1. INTRODUCTION

Hydrography is a branch of hydrology, the science of waters, which studies coastal waters, lakes and running waters, unlike oceanography, which studies deep ocean waters, particularly from the phisical and biologic aspect. The main object of hydrography is safety of navigation and is in shipping also called marine cartography. Seafarers have been using various navigational charts for a long time and lately, apart from paper charts, also electronic navigational charts, be it raster or vector. Although the use of vector and raster charts seems simple, a closer look shows us that this is not really the case, as it requires a thorough knowledge of electronic navigational systems.

2. GENERALLY ABOUT NAVIGATIONAL CHARTS

Navigational charts are one of the seafarers' oldest and most widely used navigational aids. They represent a working area on which the navigator plots courses, ship's position in the absolute sense on

the earth's surface and in the relative sense relative to the surrounding conspicuous objects and other vessels. The Hydrographic Dictionary [1], defines navigational charts as:

A chart specifically designed to meet the requirements of marine navigation, showing depths of water, nature of bottom, elevations, configuration and characteristics of coast, dangers and aids to navigation.

Navigational charts have also an important legal meaning. In case of an accident (e.g. grounding or collision) they represent relevant evidence for the reconstruction of events and help determine the cause.

2.1. Types of navigational charts

With respect to the way of displayed data there are two types of navigational charts:
- classical or paper,
- electronic.

The latter are further divided as:
- vector,
- raster.

2.2. Classical navigational charts

Paper charts are the most fundamental tools available to the mariner world-wide. They have been known and used for a long time, as they are basic for safe navigation. They offer a graphic portrayal of the marine environment on paper, such as objects in different colors, size, symbols, abbreviations and descriptions. We should make distinction between the worked out paper chart and the aero snapshots of the coast and the coastal waters. The aero snapshots are the mere image of the sea, where we can only sea a buoy, a lighthouse and a coastal line. Such an image is not enough for a mariner to sail safely, but he needs more data. These are provided by the worked out charts which present, apart from the coastal line, also the lighthouse features, sea depths, underwater objects (e.g. wrecks) as well as other important objects for safe navigation.
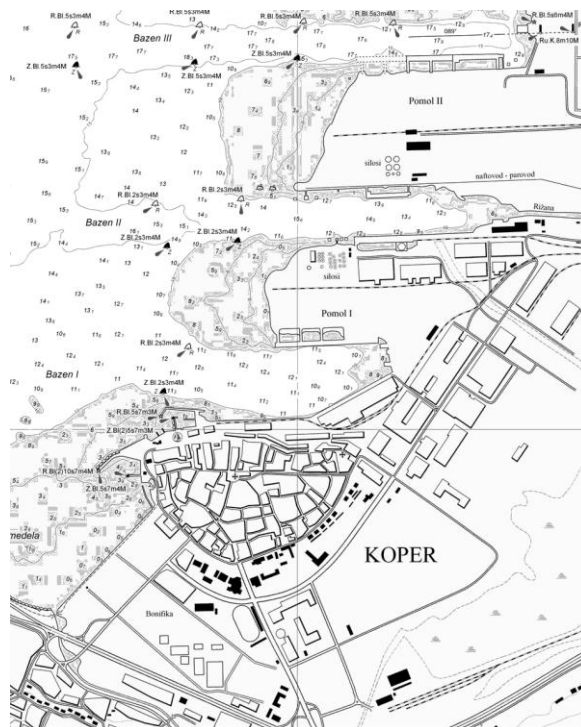
Fig. 1. Extract from a classical paper chart – The Bay of Koper
Rys. 1. Wycinek z klasycznej papierowej mapy morskiej – Zatoka Koper

2.3. Vector navigational charts

The vector display of digital data is one of the two ways of presenting navigational data on the computer monitor. The individual data are displayed in the form of direct relation between the two points by means of two coordinates or the distance and course from one point to the other.
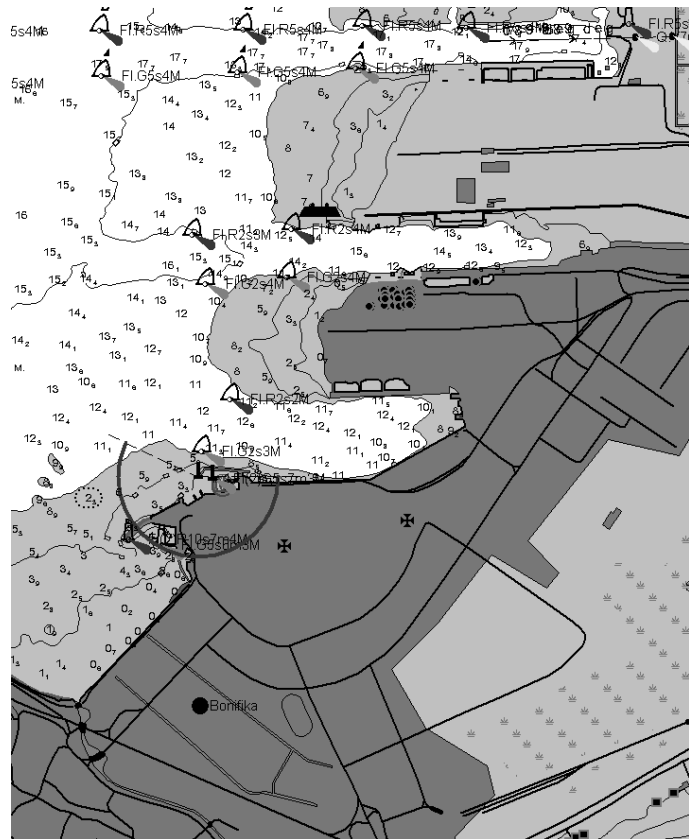

Fig. 2. Extract from the vector chart (ENC) – The Bay of Koper
Rys. 2. Wycinek z wektorowej mapy nawigacyjnej (ENC) – Zatoka Koper

2.4. Raster navigational charts

The raster display is a different way of presenting digitised data. It is simply a photographic image of the original official paper charts. This image is built up of a large grid of tiny colored dots. In the similar way is created a television image. The color of individual dots is determined while scanning the paper charts.

2.5. Requirements of the SOLAS convention

The rule 19 of the chapter V. of the SOLAS convention (*International Convention for the Safety of Life at Sea)* – precisely defines which navigational equipment a ship should carry on board. The rule requires that all ships, irrespective of their size, should carry on board publications for voyage planning and monitoring as well as the backup arrangement systems in case of failure of the electronic system, i.e. ECDIS, which is the only electronic system that complies with the convention requirements.

The regulations also provide that the ECDIS can operate in the RCDS mode (with the use of official raster charts RNC), but only where ENC are not available and together with an appropriate folio of paper charts.

3. ELECTRONIC NAVIGATIONAL CHART DISPLAYING SYSTEMS

The user of electronic navigational charts needs a system to be able to display it on the computer monitor. The electronic chart display system is in many respects among the first ship's navigational systems which use the elementary components of the information technology.

All electronic chart display systems (further: electronic systems) do not have equal performance standards or functions. The main differences above all refer to:

- format and the data content of a navigational chart,
- navigational chart display,
- available navigational functions [4].

On the basis of these criteria three elementary electronic systems are known (Hecht et al, 2002):

- Electronic Chart System – ECS;
- Electronic Chart Display and Information System – ECDIS;
- Raster Chart Display System – RCDS.

These systems are further presented more in detail.

3.1. ECS

All systems which complies with the requirements of the IHO (*International Hydrographic Organization*) and the IMO (International Maritime Organization) can be referred to as the ECS – *Electronic Chart System*. There are two reasons for this claim:

- The systems do not use official electronic charts issued by the national hydrographic office;
- Their performance standards are limited and do not comply with the IMO [4].

Some private manufacturers of the equipment and vectorized charts received permission by national hydrographic offices. These manufacturers have already become recognized on the market. A lot of their systems are efficient and functional enough, and some of them can even display official vector or raster navigational charts. Nevertheless, private manufacturers can offer only a limited integrity of the electronic charts, together with their maintenance, and therefore these manufacturers cannot comply with the rigorous standards required by the IHO and IMO. Hence, electronic charts cannot be considered as a substitute for paper charts. However, the ECS was received by users quite well, so that, generally speaking, the idea of electronic charts caught on.

3.2. ECDIS

The Electronic Chart Display and Information System must be capable of much more than only displaying electronic charts on the computer monitor. As the ECDIS is the ship's navigational system it must comply with the IMO regulations and offer a variety of navigational functions. It must be connected with other sensors important for navigation (such as GPS, radar, echo sounder etc.). As the ECDIS is also an information system, it should, apart from a graphical display of the electronic chart on the monitor, also offer the features of the displayed objects. Within the ECDIS the ENC (Electronic Navigational Chart) consists of additional optional information on other navigational functions, such as alarm anti-stranding signals.

3.3. RCDS

The Raster Chart Display System is a scanned raster image of the navigational chart. When such a chart is adequately displayed on the monitor of the navigational system, it is an authentic reproduction of information, which is comprised in the paper chart.

The legal status of the complex RCDS is currently the subject of a wider debate world-wide and does not yet entirely comply with the SOLAS convention, unlike the ECDIS. The RCDS was developed particularly because of the immediate use of electronic charts. Some larger hydrographic offices therefore developed their own electronic systems for the display of raster charts and within

their complete supply, together with the charts and their maintenance, offer them to the users. These are particularly offices, which have in their portfolio a large range of paper charts with which they practically cover the whole world. These charts are now reproduced in the raster form and put on the market also in the electronic form.

Table 1

Survey of electronic chart display systems

System	Mode	Data form	Chart type
ECS *Electronic Chart System*	**Basic**	Various format (depending on the manufacturer)	Raster **unofficial**
ECDIS *Electronic Chart Display and Information System*	**Basic**	**ENC** *Electronic Navigational Chart*	Vector **official** (format S-57)
	RCDS *Raster Chart Display System*	**RNC** *Raster Navigational Chart*	Raster charts **official**

3.4. Combination of the ECDIS and RCDS – "dual fuel"

The raster electronic systems, such as the ARCS, manufactured by the British hydrographic office, take advantage of the system which constantly supplies the users with the official charts, covering the majority of the world seas. Since the manufacturing and distribution of the official ENC is only at the beginning, the ARCS may very well supply the electronic systems which are capable of displaying vector and raster charts. The concept using both types of the electronic charts in the electronic system is now referred to as the "*dual fuel model*". This concept was given a "green light" by the IMO in December 1998. Such a system is a good solution for the users. As long as the market is not entirely covered with the ENC, they will be able to use raster charts and as soon as the ENC is available instead of the previous RNC, the users will be able to simply replace the charts, without having to change the whole system, which will reduce enormous costs.

The operation of the ECDIS in the RCDS mode still remains an option. It does not mean that each ECDIS has also the option to operate in the RCDS, and the RNC is used only as a "means to fill the gaps". Thus the charts like ARCS, BSB or Seafarer, may be used only there where the ENC is not available yet.

3.5. The difference between the ECDIS and RCDS

The IMO distributed a circular in 1999 containing the list of differences between raster and vector charts. The main goal of the list was to acquaint mariners with advantages and disadvantages of individual electronic systems and the types of electronic navigational charts.

Contemporaneously they changed the basic operation requirement of the ECDIS, as follows:
- to operate in the ECDIS mode while using the ENC,
- to operate in the RCDS mode when the ENC are not available.

The RCDS does not have equal capacity to operate as the ECDIS; therefore the said list may be used as the survey of differences. As these may be crucial in navigation, particularly when the user is unaware of that, the IMO wanted to draw attention to the importance of the awareness of these differences:

1. with the ECDIS we obtain the ENC without boundaries, while RCDS is a chart-based system similar to paper charts;

2. data in the RNC will not trigger automatic alarms (e.g. anti-grounding). But some alarms can be generated from the user (e.g. safe isobate, individual dangers or navigation obstacles, dangerous zones);
3. horizontal datum and projections may vary between individual RNC, which may reflect in the position shift. The ENC operate in the uniform system;
4. individual objects in the RNC cannot be removed or adjusted, in order that the finished chart display could be adapted to the requirements of individual users (user-selected mode). This may reflect in the excessive loading of the monitor and thus reduction of transparency while switching the content of electronic chart and radar or ARPA (*Automatic Radar Plotting Aid*) [6] ;
5. the look-ahead capability is with the RNC limited due to the impossibility of the chart scale alteration;
6. orientation of the RNC only to *course-up* or *route-up* may affect readability of text or symbols;
7. by clicking on individual items or objects with the RNC it is impossible to obtain additional attributes about the latter;
8. with RNC it is impossible to display a safe isobate or water depths and highlight them on the display, unless these features are manually entered during route planning; with RNC there may also be differences in colors used during day and nighttime;
9. The RNC is supposed to be displayed in the scale of the paper chart. Excessive zooming may cause that the chart is unreadable;
10. mariners should be aware that in narrow waterways the accuracy of charts (paper, ENC or RNC) is lower than the accuracy of the position-fixing system with RNC different multi-color shades are possible on charts, which may reflect in the different color display day/night used. The ECDIS with the use of ENC enables determining the quality of data.

3.6. Comparison of electronic and paper navigational charts

The functionality and quality standards of paper charts compared to the performance standards of the ECDIS or the RCDS can be summarised in a few points [4]:
- Technical accessibility, better view and durability are probably the only criteria which make us believe that paper charts are better than the ECDIS or RCDS;
- The ECDIS may be considered better than the RCDS in all important aspects, however the elementary display of the ship's position makes them equally good;
- Except for the limited readability at certain chart scale, the RCDS is at least equal to the paper chart regarding accessibility and view, considering there is no deterioration of display of raster chart on the monitor;
- The RCDS has great advantage over the paper chart, e.g. automatic display of the ship's position, automatic navigation monitoring.

4. OFFICIALTY OF NAVIGATIONAL CHARTS

The main navigational functions, which are the same regardless of the charts used, are voyage planning, monitoring and documenting the route.
This includes particularly:
- The choice of the optimal route considering navigational and economic navigational elements;
- Ensuring that the navigation on the chosen route is safe (e.g. identification of all navigational aids, fixing position, courses made good and the speed of navigation).

Regardless of the navigational chart used, the SOLAS requirements are very clear. If the shipmaster respects these rules, he must use exclusively only official navigational charts! It includes also electronic systems and in the latter case also safety systems in case of failures.
Which are the conditions for the officially of navigational charts:
- Charts must be issued by the national hydrographic office,
- Charts must be regularly maintained.

4.1. Maintenance of navigational charts

Mariners have been waiting for centuries to make light work of maintenance of charts and publications, which are their most important source for safe navigation.

The maintenance of charts is usually done through the Notice to Mariners. These are issued weekly, monthly or according to needs. In case of paper charts, the mariner has to correct a pile of charts, which are carried in the portfolio on the bridge. The ships carry on board from 200 to 500 charts, and some even up to 2000 charts [4, 6]. Such weekly corrections took mariners a lot of time.

In the age of electronic navigational charts this work is considerably reduced. All corrections can be entered in the system in a few minutes, and the rest of the time can be dedicated to other duties or lookout to observe the ship's surroundings.

The electronic corrections come on board in different ways. It may be with the CD, received in ports while the ship is made fast or through modern ways of communication, such as e-mail or website. The corrections are then automatically downloaded in the system and thus are corrected all charts to which the corrections refer. However, the user still has the possibility to enter corrections manually.

The supply of corrections and charts to ships via website, e-mail or the INMARSAT is very welcome. Thus the ship may enter ports with the up-to-date data, particularly when there have been important changes of routing since her last approaches to the same port.

4.2. Official navigational charts

When we speak about official navigational charts, we mean the charts issued by the national hydrographic office. This applies to paper and electronic charts. Regarding paper charts there was no doubt whether they were official or not, as they were always issued by national hydrographic offices. However, in the age of computer technology the situation changed. Among bidders of electronic charts companies appeared like mushrooms after the rain, which digitised charts (into raster or vector form). These charts are now offered as individual products or as a complete bid, together with the chart display.

The critical difference between the ECDIS and the ECS is the very officially of charts. Referring to the last amendments of the SOLAS convention (June 2002), the ECDIS complies with the requirements to carry adequate updated charts on board, while the ECS do not comply with these requirements. Therefore all those who use the ECS, apart from electronic charts, should have also paper charts. But the ECDIS is official and meets the requirements of the SOLAS convention in case the ENC are used.

It is somehow different with the official RNC. These are raster charts, which are like the ENC manufactured and issued by national hydrographic offices. The difference between other raster charts is again in their officially, which is ensured by the national hydrographic office. Here it is important to point out when such charts may be used and under which conditions to be considered official. They may be used in the ECDIS, operating in the RCDS mode. Such charts can be used only when for the same area ENC do not exist. Besides, the system must have safety provision In case of operation failure.

4.3. The failure of hardware

The ECDIS is an electronic apparatus – computer, which, like any other similar apparatus, may fail. Although the standards for the safe operation of electronic apparatuses on board ships are considerably higher than those in ordinary offices ashore; these are also vulnerable to failures. Already a simple failure of power supply on the bridge may lead to a dangerous situation. Such occurrence is usually solved by the use of batteries (so called UPS). There is also a possibility of the failure of individual computer components of the ECDIS. Also in such cases there must be a provision of an independent power supply source to take over the main navigation functions.

Unfortunately there is no system which is 100% reliable and this very fact represents the greatest challenge and doubts to the manufacturers and to the users before use. It is impossible, considering a reasonable price, to produce an electronic system, which would not be subject to failure.

The IMO was aware of this while preparing regulations and requirements for the operation of the ECDIS. This particularly means:

- Equipment for safe takeover of the ECDIS functions, so that the failure would not lead to a critical situation,
- Means to ensure safe navigation for the rest of voyage to the nearest port in case of the ECDIS failure.

As provided by the IMO, ships must ensure the takeover of navigation in case of the primary ECDIS failure. Here the main issue appears as to what means "adequate back up arrangements", as the requirement provides. Different states interpret these regulations differently, particularly the term "adequate", and consequently they make up their own laws. This causes inconveniences with the ECIDS users, as they cannot enter ports under the same conditions.

Among options, regarding the takeover of navigation in case of ECDIS failure, the following are complying with the SOLAS convention:

- Entirely independent back up arrangements for the ECDIS,
- The ECDIS, which operates in the RCDS mode, together with the official RNC and an *appropriate folio* of paper charts,
- Updated paper charts.

In the second item the word *appropriate folio* is stressed. This very collocation causes inconvenience and doubt among users and states, as there is no particular definition what an *appropriate folio* denotes. The ship-owners will not invest in the expensive navigational system, such as the ECDIS, if they should still carry on board numerous paper charts which must be manually updated, and at the same time download the updating of the ECDIS charts. It signifies double work, which is quite contrary to the main intention of the ECIDS introduction, i.e. reduction of work done in updating the enormous folio of paper charts!

5. CONCLUSION

There is no doubt that navigational charts are one of the main mariners' aids for safety of navigation. The shift from paper to electronic charts is not simple and cannot be carried out overnight. The procedure requires numerous hydrographic measurements, creating of new charts, organisation and management of hydrographic database, manufacturing of electronic chart display systems, and last but not least adequate training of seafarers.

Not only that charts must be an authentic representation of natural objects but they must also be properly and regularly maintained. For the electronic charts the requirements are even higher. The ECDIS should be official and must use official ENC. However, in case the latter are unavailable, the official RNC may be used, together with an adequate folio of paper charts carried on board and back up arrangements in case of failures.

Electronic charts made a great contribution to safety of navigation, considering they are appropriately applied, the principle of their operation and all their functions are known.

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